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The Great Escape: Technological Lock-in vs Appropriate Technology in Early Twentieth Century British Manufacturing

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November 2013

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The Great Escape: Technological Lock-in vs Appropriate Technology in Early Twentieth Century British Manufacturing*

Pieter Woltjer[†]

November 18, 2013

Abstract

America's lead over Europe in manufacturing productivity from the late nineteenth century onwards has often been contributed to differences in initial conditions, trapping Europe in a relatively declining, labor-intensive and low-productive technological path. In this paper, I reassess the productivity dynamics in British manufacturing on the basis of a novel analytical framework by Basu and Weil that emphasizes the role of learning and localized technical change and which predicts convergence in light of rapid capital deepening. By means of a data envelopment analysis, I measure the effects of capital accumulation, technological change, and efficiency change. I find evidence for considerable increased capital-intensity levels in British manufacturing during the early twentieth century, particularly in the 'new' industries which actively began to adopt modern techniques of mass-production and managerial control. My findings seriously challenge the traditional, declinist, technological lock-in hypothesis. Instead, the British shift toward mass-production techniques during the interwar period provides a strong case for a remarkable escape from the labor-intensive path which had held the British manufacturing sector in its grasp throughout the nineteenth century.

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1 Introduction

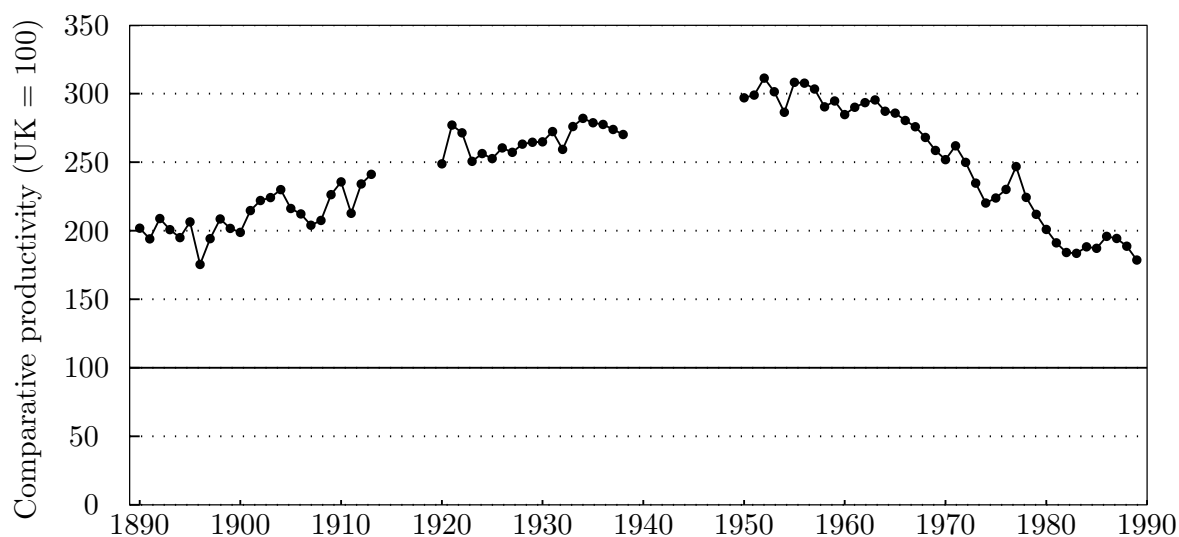
From the late nineteenth century onwards the US forged ahead of Britain in terms of productivity levels. Britain's, as well as other European countries' falling behind during the nineteenth century and their inability to catch-up has traditionally been explained by local circumstances; i.e. factor and resource endowments as well as demand patterns (Habakkuk 1962). In Europe natural resources were scarce, whereas skilled labor was in ample supply. This provided European producers with an incentive to economize on fixed capital in the form of machinery (Temin 1971, 162; Field 1985, 379). In contrast, the US was well endowed with natural resources, while skilled labor was relatively expensive. Therefore, machinery was substituted for skilled labor, resulting in a capital-intensive production process. Furthermore, as the American demand for goods was more homogenous, manufacturers could standardize production methods and implement high throughput systems, thereby raising productivity levels (Broadberry 1994, 291). This advantage was denied to European producers, who faced heterogeneous markets characterized by a demand for customized goods.¹ Thus, local circumstances determined the initial choice of technology. Technological progress was subsequently directed toward the particular technological path a country had chosen, leading to lock-in effects. Particularly David (1975, 66) puts path dependency center stage when explaining the evolution of distinctive transatlantic systems of production. In this view, a major shift in technology applied, for any country, is only feasible if relative factor prices change dramatically.

As illustrated by de Jong and Woltjer (2011), the transatlantic productivity gap, which had evolved to a ratio of around 2:1 by 1900, continued to widen up to the 1950s (see figure 1). Broadberry (1994, 292; 1997, 3) argues that this lack of productivity convergence reflected the persistence of distinct industrial technologies in Europe and the United States. European producers continued to pursue a crafts-based production system, losing both productivity and technological leadership to the American system of mass-production that, up to the 1970s, proved to be technologically more progressive. In the period since the 1970s, according to Broadberry, craft production once again became more progressive and technological leadership reverted back to Europe. For the case of British and American industrial performance, the premise of the coexistence of two distinct industrial systems is strengthened by time-series evidence which finds that, after 1870, the productivity gap between both countries was non-stationary and divergent (Greasley and Oxley 1998, 184). This non-stationarity suggests that industrial productivity followed different, independent paths, which precludes an important role for technology transfer.

As pointed out by Bowden and Higgins (2004, 383–4), the problem with the above interpretation is that it is essentially static. “It traces the misfortunes of the interwar years

1. Note that recently Hannah (2008) has argued against the hypothesis of large heterogeneous European markets and small-scale production, illustrating his point with evidence of relatively low transportation costs and integrated markets in Europe prior to 1914.

Figure 1: Output per hour worked in manufacturing, US and UK (UK=100, 1890–1990)



Source: de Jong and Woltjer (2011, 487).

to technical choices made in the previous century which depended upon specific supply- and demand-side factors. It presumes that demand can be taken as given and that supply adjusted accordingly, rather than allowing for the possibility that supply-side changes may create new demands. It lacks the possibility of change, of adaption to different conditions and changes in resource constraints.” Basu and Weil (1998) developed an alternative analytical framework which illustrates that, regardless of static differences in factor and resource endowments or demand patterns, countries have the potential to rapidly converge in terms of labor-productivity levels if they successfully adopt the leaders’ production technologies. They emphasize the fact that technological change appears to be biased toward the capital-intensive technologies and that spillovers occur only in a limited range of technologies. Countries operating on a technical level far below the range of the world’s technology leaders are thus likely to fall behind in terms of productivity growth. This will eventually induce them to adopt more capital-intensive production techniques in order to benefit from knowledge spillovers. The mechanics behind this type of technology transfer are also regarded by Aghion (2008, 31) and various other scholars who argue that countries distanced far away from the productivity frontier can catch-up by applying an investment-based growth strategy, provided that the necessary capabilities and resources – mainly primary and secondary education – are available (Acemoglu 2002, 39; Vandenbussche, Aghion, and Meghir 2006, 98). The speed at which countries are likely to converge is not only dependent upon the size of the technology gap and the rate of capital deepening (their savings rate), but is constrained by the effects of learning by doing and other barriers that raise the cost of adopting a higher level of technology as well (Barro and Sala-I-Martin 1997). These ideas build upon

what Abramovitz (1986, 387) refers to as ‘social capabilities’ and Gerschenkron (1962, 113) ‘appropriate’ economic institutions to encourage technology adoption.

A number of recent studies have found empirical evidence that strongly supports Basu and Weil’s appropriate-technology hypothesis (Kumar and Russell 2002; Los and Timmer 2005; Timmer and Los 2005; Caselli and Coleman 2006; Allen 2012). These studies rely on a novel framework, the data envelopment analysis (DEA), that emphasizes the role of technology and the potential for technology transfer; factors that, thus far, have received little attention in the empirical convergence literature (Bernard and Jones 1996, 1037–8). They confirm the importance of localized innovation – i.e. technological improvement that is confined to a particular mix of capital and labor, or more generally, is restricted to a range of similar technologies – and stress the finding that global technological change is decidedly biased toward capital-intensive production techniques. This appears true both for the period prior to and following the Second World War (Atkinson and Stiglitz 1969, 574; Kumar and Russell 2002, 529; Allen 2012, 4–5). The strong bias toward capital-intensive techniques in conjunction with the exceptionally progressive nature of technological change during the early twentieth century, as stressed by authors such as Gordon (1999) and Field (2003)), is likely to have induced European entrepreneurs to increase their rate of capital deepening and adopt American production techniques. This hypothesis is in stark contrast to the static David model of divergent transatlantic technological paths, adhered to by Broadberry for the twentieth century.

In this paper I adopt the DEA framework and apply it to the case of productivity and technology convergence in Britain and the United States. The aim of this paper is threefold. First, I want to confirm whether technological change in manufacturing during the first half of the twentieth century was localized (i.e. whether the assumption of factor neutrality can be rejected). The second aim is to show empirically whether British industries continued to innovate along their own labor-intensive productivity path (David’s model) or, if they actively sought to adopt American techniques by accumulating physical capital, to benefit from the rapid technological change at the capital-intensive side of the production frontier (Basu and Weil’s model). The third and last aim of this paper is to quantify the effects of technological change, capital deepening, and barriers to technological diffusion on labor productivity growth at the industry level. This will provide a novel view of the dynamics behind the trans-Atlantic labor-productivity differentials during the early twentieth century.

For this purpose I have constructed a new set of internationally comparable, industry-specific output, employment and capital measures, spanning the period 1899 to 1939. As convergence in terms of labor productivity driven by technology diffusion typically occurs at the level of products or industries rather than at the total economy level, I retain a highly disaggregate level of analysis on the basis of original census data (Timmer and Los 2005, 48). This allows me to study technological change and transfer at the industry level, which sets my study apart from previous studies that typically maintained a strong macroeconomic

viewpoint.

In this paper my primary interest lies in the measurement of technology convergence rather than its causes. Not because I think that a search for the causes of the patterns of efficiency is unimportant, but because I feel uncovering the pattern comes first. My findings should be interpreted as being complementary to existing explanations in either the neoclassical or endogenous-growth literature that model the impediments to technology transfer, as well as traditional explanations of the British growth experience during the early twentieth century. The model and the decomposition exercise is explained in section 2. In this section I will also, briefly, discuss the construction of the data set. Section 3 presents the main results, which are considered in light of the current debate on British technological change in section 4. Section 5 concludes.

2 Methodology and data

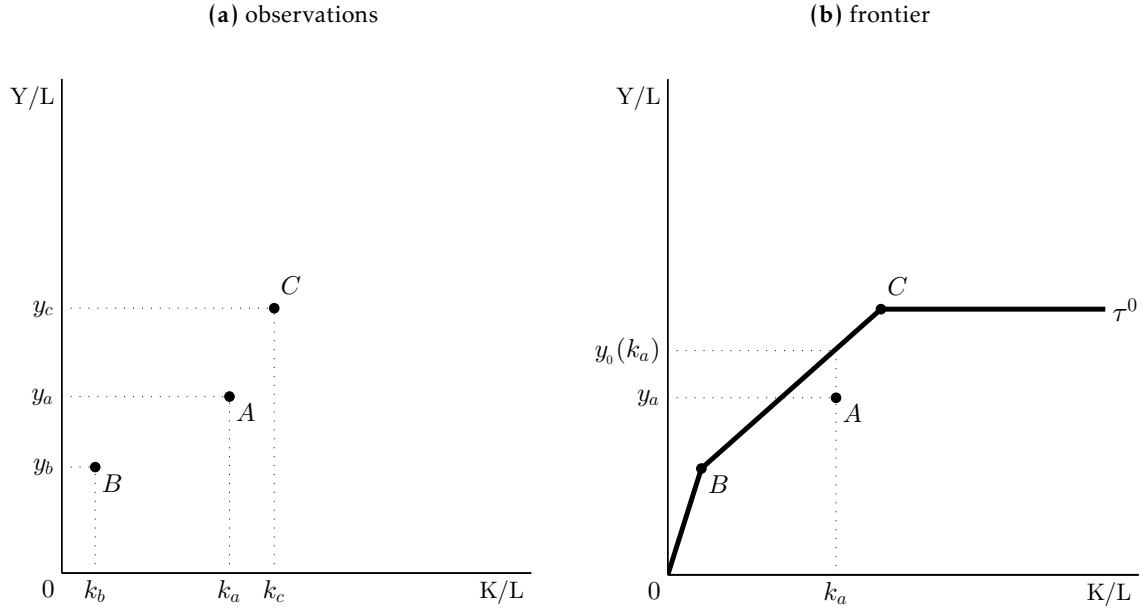
For my study of productivity dynamics in Britain and the United States I apply a data envelopment analysis (DEA) and perform the decomposition technique recently proposed by Kumar and Russell (2002). The DEA approach allows me to estimate a global production frontier which represents the various ‘best practice’ production techniques observed for the entire feasible range of input combinations. By tightly enveloping data points with linear segments using mathematical programming methods, the structure of the frontier can be revealed without imposing a specific functional form on either technology or deviations from it (Färe, Grosskopf, and Lovell 1994, 12–3). Because of its non-parametric nature, the DEA naturally allows for any form of localized technical change, an important feature in my framework (Los and Timmer 2005, 522). This approach also lends itself more readily to the decomposition of productivity growth as, in contrast to traditional growth-accounting exercises, it distinguishes between both the effects of (global) technological change and relative efficiency change. In later sections I will show that efficiency loss, i.e. the movement away from the frontier, is a crucial factor in explaining the British growth dynamics during the early twentieth century.

Data Envelopment Analysis

Figure 2 depicts a basic example of a DEA involving three producers which use two inputs (capital K and labor L) to produce a single output (Y). Assuming constant returns-to-scale, I can represent the world production frontier in $\langle k, y \rangle$ space, where y is labor productivity (Y/L) and k is capital intensity (i.e. individual production techniques, K/L).

As noted above, the frontier (τ) for the observations in figure 2 is formed as linear combinations of observed extremal activities or, following the definition by Salter (1966), ‘best-practice’ activities. An observation is said to be a best-practice activity if it exhibits full effi-

Figure 2: Illustration of data envelopment



ciency in the Koopmans (1951, 460) sense, who defined an activity as technologically efficient if increasing any output or decreasing any input is possible only by decreasing some other output or increasing some other input. As illustrated in appendix C, the identification of these fully efficient observations can be reduced to a basic linear programming problem in the form of a distance function (Färe et al. 1994, 68–9).

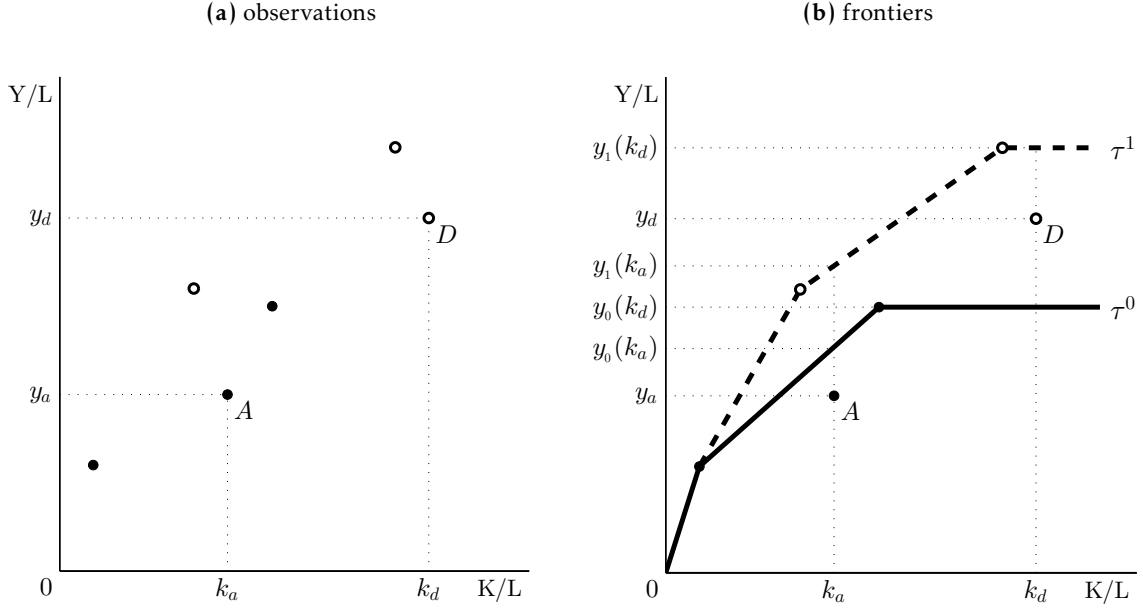
Of the three observations in this example, only B and C are classified as best-practice techniques. The frontier is formed by tightly enveloping these two fully efficient observations with linear segments, as illustrated in the right-hand panel of figure 2. The frontier is thus a subset of all feasible techniques that attain the highest labor productivity for the capital intensity levels they correspond to (Timmer and Los 2005, 52).

The panel on the right-hand side of figure 2 also shows that the last remaining observation (A) is located below the frontier. Observation A 's vertical distance to the frontier indicates the potential for labor-productivity increase. Farrell (1957) shows that this distance can be interpreted as a measure of technical efficiency. In figure 2, the ratio of A 's observed productivity y_a to the optimal productivity level at A 's capital-intensity $y_0(k_a)$ represents the Farrell efficiency index.

Decomposition

The frontier approach can be used in a decomposition of total-factor productivity (TFP), a process described by Kumar and Russell (2002, 528–9) as 'growth accounting with a twist'. They break down TFP growth into two components: [1] technological catch-up, and [2] technological change. They characterize the first component as movements toward (or away from)

Figure 3: Illustration of growth decomposition



the frontier, as countries adopt best practice technologies and reduce (or exacerbate) technical and allocative inefficiencies. The second component reflects shifts in the global production frontier, determined conceptually by the state-of-the-art, potentially-transferable, technology. To decompose labor productivity growth, rather than TFP growth, the effects of capital accumulation can be added, which reflect movements along the frontier (Timmer and Los 2005, 50).

To illustrate this decomposition, I have extended the example of figure 2 to include a second period. As shown in the left panel of figure 3, the example now includes six observations: the three original observations from period 0 and three new observations for period 1. To form the new frontier, I again utilize the distance functions to locate the fully efficient observations among the six in the sample. These observations are then enveloped by linear segments. Both the new frontier as well as the original period 0 frontier are shown on the right-hand side of figure 3.²

The panel on the right-hand side of figure 3 also displays two inefficient observations (A and D) which represent the same producer at time 0 and 1 respectively. Labor-productivity change, between these observations A and D, can be decomposed according to equation (1) below

2. Note that the period 1 frontier (τ^1) in figure 3 consists of observations from both the first and the last period. As a result, the frontier will only shift outward as I will discuss below.

$$\frac{y_d}{y_a} = \underbrace{\left(\frac{y_d}{y_1(k_d)} \bigg/ \frac{y_a}{y_0(k_a)} \right)}_{\text{efficiency}} \cdot \underbrace{\left(\frac{y_1(k_a)}{y_0(k_a)} \cdot \frac{y_1(k_d)}{y_0(k_d)} \right)^{0.5}}_{\text{technological change}} \cdot \underbrace{\left(\frac{y_0(k_d)}{y_0(k_a)} \cdot \frac{y_1(k_d)}{y_1(k_a)} \right)^{0.5}}_{\text{accumulation}} \quad (1)$$

The first right-hand side factor measures the change in the Farrell efficiency index. A value larger than 1 represents an increase in the level of technical efficiency over time; hence, I denote this as the *efficiency* component. The second factor, *technological change*, measures the increase in labor productivity as a result of a shift in the frontier. Since the vertical shift of the frontier can be observed both at capital intensity k_a as well as k_d , I adopt a ‘Fisher ideal’ decomposition and report the geometric average of the two measures. The last factor, which I label *accumulation*, is a Fisher index of the potential change in labor productivity resulting from a shift in the capital-labor ratio. This component represents the average productivity gains or losses as a result of the movement along both frontiers.

Extensions to the basic model

For my analysis, I have made a number of additions to the basic framework described by Kumar and Russell. First, I adopt an ‘intertemporal’ approach, in line with the empirical analysis of Los and Timmer (2005).³ Instead of estimating the frontier at time t based solely on observations from this period, I also include all observations prior to period t in the production set. Los and Timmer (2005, 522–3) argue that there are two important reasons to adopt the intertemporal approach:

“First, because the production frontier is constructed sequentially, it can never shift inward and hence ‘technological regress’ cannot occur. The possibility of ‘technological regress’ seems awkward and hard to defend from a knowledge perspective on technology, as it would involve ‘forgetting’. Second, a crucial element in the [Basu and Weil] model is the possibility for countries to use knowledge that was generated by technology leaders in the past. Labor-productivity levels of past technology leaders should be attainable for latecomers.”

A potential problem is that frontier techniques observed for the first year in my sample, 1907, could be dominated by unobserved combinations in the past. In that case, part of what would be interpreted as frontier movements would in fact be assimilation of knowledge associated with these unobserved appropriate techniques. To accommodate this problem, I extended the data set backwards by 8 years and included two additional periods for the US, 1899 and 1904 respectively.

3. For a discussion of the time component in data envelopment analysis see, Tulkens and Vanden Eeckaut (1995).

Secondly, I address the issue of aggregation. So far, the level of aggregation in the frontier analysis literature has been highly macroeconomic. Kumar and Russell (2002) for the post-WWII period and Allen (2012) for the nineteenth and early twentieth century, for instance, rely on a global production frontier for the total economy. Bernard and Jones (1996, 1043) show that sectoral measures of productivity growth and convergence can look very different from aggregate results. Convergence in terms of labor productivity driven by technology diffusion typically occurs at the level of products or industries, rather than at the total economy level. As pointed out by Timmer and Los (2005, 48), “Convergence at the industry level might not be reflected in macroeconomic statistics when countries differ in their industrial composition or experience different patterns of structural change.” Broadberry (1997, 63–73) indeed observes substantial differences in the sectoral composition between Great Britain and the US for the early twentieth century. Hence, I focus solely on manufacturing, which has the biggest scope for technology spillovers. In addition, I break up the manufacturing sector into twenty-seven industry-groups and estimate a separate global production frontier for each.

Data

For the analysis of transatlantic labor-productivity differentials between 1907 and 1930, I have constructed a new data set of industry-specific real value added, employment and capital statistics. My panel observes ten benchmark years for the US (spanning the period 1899 to 1939) and two years for Great Britain (1907 and 1930). In addition, I also included two benchmark years for Germany (1907 and 1936).⁴ The set thus includes data for the three greatest industrial nations of the early twentieth century, covers approximately 105 separate industries and overall consists of nearly 1,500 observed input-output combinations.

The capital data is based on horsepower statistics, a proxy for the stock of machinery and equipment. I focus on machinery rather than the total capital stock for two reasons: [1] the horsepower statistics are available at a highly disaggregate level allowing me to study productivity at the individual industry level and [2] DeLong and Summers (1991) show that there is a much stronger association between investment in equipment and machinery and economic growth than any other other component of investment. Innovations are embodied in machinery to a far greater degree than is the case for buildings and intermediate inputs.

The basic source for US industries is the *Census of Manufactures*, while the primary British data is taken from the First and Fourth *Census of Production*. German data is drawn from multiple industrial surveys, statistical yearbooks, employment censuses as well as the archival records of the 1936 *Industrial Census*. This section will briefly describe the basic methods behind the construction of the data set. A full description of sources and methods can be found in appendices A and B.

4. The results for Germany are discussed in a separate working paper; see Veenstra and Woltjer (2012).

As a first step in the construction of my data set, I reclassified the industrial data for all three countries and all years to the 1945 US Standard Industrial Classification (SIC).⁵ Generally, an industrial classification groups establishments primarily engaged in the same line, or similar lines, of economic activities. In the case of manufacturing this is either defined in terms of the products made (demand side) or the processes of manufacture used (supply side) (Kendrick 1961, 405–6). The SIC scheme places primary emphasis on the latter, whereas the original, pre-war, British, German and American classifications rely heavily on the former. The supply-side grouping of businesses – i.e. the categorization according to the way in which inputs are transformed into outputs, mainly depending on the technology used – fits neatly into the DEA framework.

To make the British output data directly comparable to the US, I relied on the price conversion by Frankema, Woltjer, and Smits (2013) and de Jong and Woltjer (2011).⁶ The industry level conversion factors, or Purchasing Power Parities (PPP), were calculated on the basis of producer prices using the procedures first set out by Paige and Bombach (1959) and extensively delineated in the work of van Ark (1993, 25–52). To make the German data comparable to the US, I turned to two new, as yet unpublished, benchmark studies for 1907/09 and 1935/36 based on the same methodology.⁷ These PPPs enabled me to convert British and German value added into nominal dollar values, both prior to and following the First World War.

Nominal value added in dollars for all three countries was then converted to constant prices (with a 1929 base) by applying US price deflators at the industry level. I calculated deflators on the basis of the Fabricant (1940, 123–321, 605–39) indices of physical- and nominal-output series. Subsequently, I reclassified these deflators to fit the SIC, and incorporated the modifications and extensions to the indices of production proposed by Kendrick (1961, 416–21, 467–75). Lastly, I expressed the employment measure in terms of hours worked and adjusted my capital measure to exclude the power of electric motors run by current generated in the same establishment. The adjustment to the measure of the capacity of horsepower was made in order to prevent the duplications of motors effectively driving the same machinery. The necessity of the hours adjustment has been stressed by de Jong

5. For an overview of the SIC, see United States Department of Commerce (1949b, 862–914).

6. Note that the interwar Anglo-American benchmark refers to the year 1935, whereas the British production figures for this study are based on the 1930 census returns. To convert British value added to 1935 dollars I have taken the output-price changes between 1930 and 1935 for Great Britain into account. For Britain, I extrapolated the 1935 PPPs to a 1930 base using price deflators taken from the work of Feinstein (1972). See appendix B for further details.

7. The price data for the German interwar benchmark was collected from the American 1935 Census of Manufactures as well as the German Industrial Census of 1936. The sources and methods used were identical to those described in the recent 1935/36 British-German benchmark by Fremdling, de Jong, and Timmer (2007) and the 1935 British-American benchmark by de Jong and Woltjer (2011). For the pre-war benchmark, US price data was again taken from the 1909 Census of Manufactures. German, manufacturing-wide production censuses did not become available until after the First World War. For the early benchmark, data is obtained from industrial surveys, which reported output and prices for a sample of industries between 1907–1912, see Veenstra and Woltjer (2012).

and Woltjer (2011), who recount the substantial drop in the average hours of work for the interwar period, particularly for the US.

My data set thus includes a single measure of output (value added in constant 1929 dollars) and two inputs (hours worked and horsepower capacity), similar to the example discussed above. I also assume constant returns-to-scale throughout this paper.⁸ As previously noted, I estimate a separate frontier for twenty-seven industry groups. These industry groups are referred to as two-digit industries; a denotation which indicates their level of aggregation as being one step above the three-digit level, the level of detail of my data set. In the estimation of the frontiers I pool all the three-digit observations belonging to the same two-digit industry, implicitly assuming that these observations share a common production function.⁹

3 Results

The main findings of this paper can be summarized in three points. First, for the first half of the twentieth century technological change at the frontier was decidedly non-neutral and biased toward capital-intensive production techniques. Because of this bias labor productivity grew fastest for capital-intensive techniques. If frontier technology was freely available to follower countries, the latter had a clear incentive to adopt capital-intensive production techniques. Secondly, in terms of capital-intensity levels, British manufacturing converged on the US between 1907 and 1930, creating a large growth potential. Thirdly, Great Britain did not take full advantage of the growth potential it had created. Despite the process of rapid capital deepening, low levels of efficiency stood in the way of Britain catching-up in terms of labor-productivity levels. These findings are more in line with Basu and Weil's model of localized technological change than David's concept of technical lock-in.

Biased technological change

In his analysis of the diverging Anglo-American labor-productivity gap David (1975) argues that the initial choice of technology, being either capital-intensive for the US or labor-intensive for Europe, led to distinctive rates of technical progress across the Atlantic. He argues that, during the nineteenth century, these distinct rates of technical progress resulted

8. Färe, Grosskopf, and Lovell (1994, 32–7) show that the flexible nature of the DEA would allow me to relax the constant-returns-to-scale assumption, this does come at a cost of greatly increased data requirements, however. A sensitivity check on the basis of variable returns-to-scale, which can be found in appendix E, demonstrates that this assumption does not significantly alter my findings. I therefore feel confident using it.

9. Note that the two-digit classification used for the frontier estimation differs moderately from the US Standard Industrial Classification. At the two-digit level the 1945 SIC only distinguishes between twenty industries. I separated a number of these two-digit SIC industries as the assumption of a common production function appeared to be invalid. In these cases I estimated more than one separate frontier for that respective group. A notable example is the *chemicals and allied products* industry. Appendix E provides a more extensive description of the selection of frontiers, as well as a sensitivity check on the assumption of a shared production function at the two-digit level. Table 4 in appendix D provides an overview of the twenty-seven manufacturing industries included in this study.

from the fact that the effect of technological advances for a particular input mix was not automatically transferred to other technologies and was essentially ‘localized’ to a specific capital-labor ratio. In similar vein, Basu and Weil (1998, 1027) argue that, although technology is freely available to all and instantly transferred, a country may nonetheless refrain from using a new technology until it reaches a level of development at which this technology would be ‘appropriate’ to its endowments. They emphasize the fact that technological change appears to be strongly biased toward the capital-intensive technologies. Consequently, countries operating on a technical level far outside the range of the world’s technology leader are likely to fall behind in terms of productivity growth, as they are unable to benefit from the technological change at the capital intensive side of the production frontier. This will eventually induce the follower countries to adopt more capital-intensive production techniques to take advantage of the technology improvements made by the leader countries in the past (Timmer and Los 2005, 49–50).

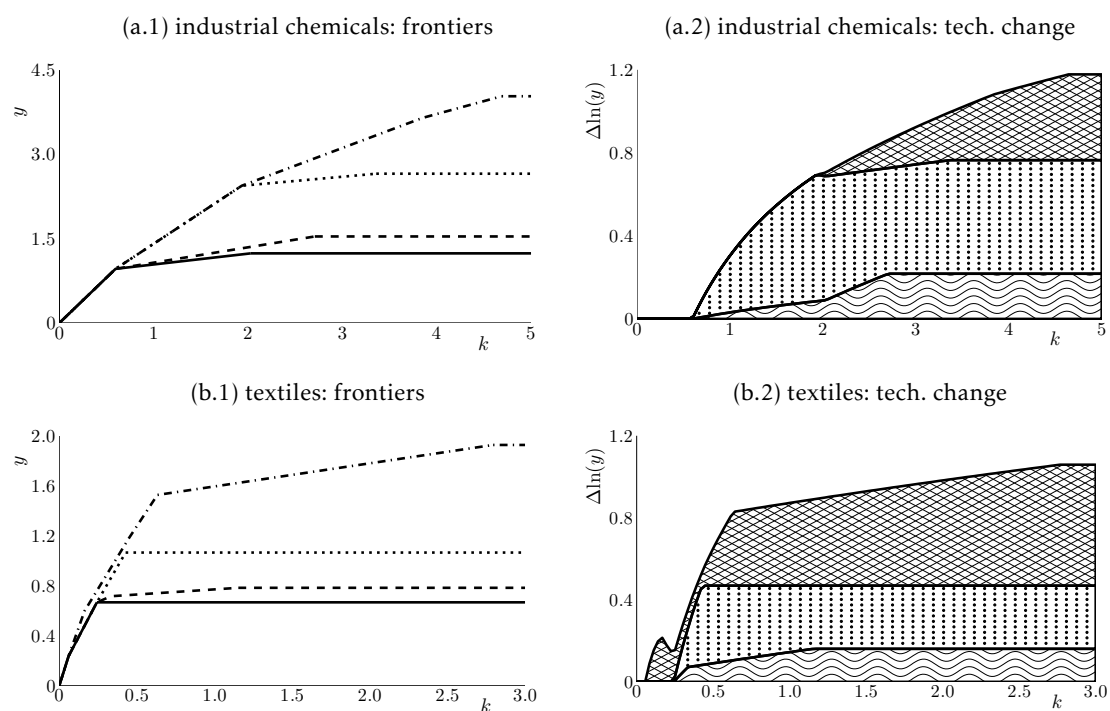
Although both these models rely on the same concept of localized technological change, David’s analysis is essentially static whereas the Basu and Weil model incorporates a dynamic element. The Basu and Weil model allows the possibility for countries to escape the technological lock-in trap which inevitably follows from David’s model. As pointed out by Bowden and Higgins (2004, 383–4), the problem with David’s interpretation is that it traces the misfortunes of the interwar years to technical choices made in the previous century and does not allow for the possibility of either supply- or demand-side changes. Basu and Weil on the other hand show that, regardless of static differences in factor and resource endowments or demand patterns, countries have the potential to rapidly converge in terms of labor-productivity levels if they successfully adopt the leaders’ production technologies.

Several empirical studies have confirmed the existence of factor-biased technical change – which stands at the heart of the Basu and Weil model – in pre-WWII manufacturing industries at the *aggregate* level (Salter 1966, 133; Allen 2012, 6). In this section I will corroborate the existence of this bias for the early twentieth century at the *disaggregate* level, particularly for those industries closely associated with the Second Industrial Revolution. The bias in technological change, for the period between 1909 and 1939, is illustrated in figure 4 for two of my twenty-seven industries.¹⁰ For both industries I include a plot of the global production frontiers on the left-hand side, in line with the example in figure 3. In addition, on the right-hand side I graph the log change in potential labor productivity as a result of the shift in the global frontier over time. This technological change is plotted for varying levels of capital intensity.

The top-most panels of figure 4 show that, for the industrial chemicals industries, technological progress is strongly biased toward capital-intensive forms of production. Technological change for producers in this industry operating at a capital intensity level of 4 horsepower per 1,000 hours of work was between 50 and 100 percent higher than for those producers op-

10. Graphs for all industries are shown in appendix D.

Figure 4: Global technological change (1909–1939)



Legend

— · — · — 1939
 1929
 - - - - - 1919
 _____ 1909

Legend

1929 – 1939
 1919 – 1929
 1909 – 1919

k = horsepower per 1,000 hours of work

erating at a capital-intensity level of 2 or less. Below a level of 0.5, technological change was absent or negligible. The picture that emerges for this industry corroborates Basu and Weil's proposition that innovation is primarily carried out by the technology leader and does not shift the production frontier as a whole. Instead, only the section of the production frontier in the direct vicinity of the innovators' combination of production factors shifts upward as a result of the technological change.

The textiles industries, on the other hand, exhibited factor-neutral technological change, as evidenced by the stable relation between capital intensity and technological change in the lower-right panel. For textiles, the increase of labor productivity as a result of technological advances were only marginally greater at a capital-intensity level of 3 compared to a level of 1. The discussion in appendix D shows that, for the majority of manufacturing industries, technological change exhibited a strong bias toward capital-intensive production techniques. Notable exceptions to this rule (i.e. textiles, leather and the foods sector) stress the importance of a highly disaggregated analysis when studying technological change and the diffusion of technology, however. I will return to this issue in the sectoral decomposition of the Anglo-American productivity gap below.

Over time, the bias of technological change shifted further toward the right into the more capital-intensive range of production techniques. Between 1929 and 1939 producers in the industrial chemicals sector operating at a capital-intensity level below 2 did not experience any further gains in labor productivity resulting from technological progress. This trend can be observed for the majority of manufacturing industries during the early twentieth century and continued after the war (Allen 2012, 5). Generally, I observe the most rapid rate of technological change between 1919 and 1929, represented in figure 4 by the area of the dotted surface. For the US, technological change contributed over 3.4 percentage points to overall manufacturing labor-productivity growth annually between 1919 and 1929.¹¹ This was considerably higher than the 1.3 points experienced during the 1910s and the 1.6 points I observe for the 1930s. The technologically progressive nature of the interwar period is also stressed by authors such as Gordon (1999) and Field (2003). The wide range of new technologies and practices, as well as the strong capital bias in technological development created a clear incentive for British entrepreneurs to increase the rate of capital deepening and adopt American production techniques.

Aggregate decomposition

Table 1 reports the average annual growth rate of aggregate manufacturing productivity for the US between 1909 and 1929 and Great Britain between 1907 and 1930. Labor-productivity growth is broken down into the contribution of capital accumulation, technological change

11. The contribution of technological change for the sub-periods is calculated on the basis of the *technological change* factor in equation (1), which represents a Fisher index of the log change in labor productivity as a result of the shift in the global production frontier.

Table 1: Decomposition of labor-productivity growth, total manufacturing, US and GB

	<i>annual average growth rate, in ln%</i>			
	<i>total</i>	<i>accumulation</i>	<i>tech. change</i>	<i>efficiency</i>
United States (1909–1929)	3.1	0.7	2.2	0.2
Great Britain (1907–1930)	1.9	1.7	1.4	-1.2
<i>Difference (US-GB)</i>	1.2	-1.0	0.8	1.4

Sources: see section 2.

and efficiency change, following the Kumar and Russell procedure illustrated in equation (1).¹² The last row of table 1 lists the difference between the average British and American rates of growth, essentially a decomposition of the gap in Anglo-American labor-productivity growth into the aforementioned components.

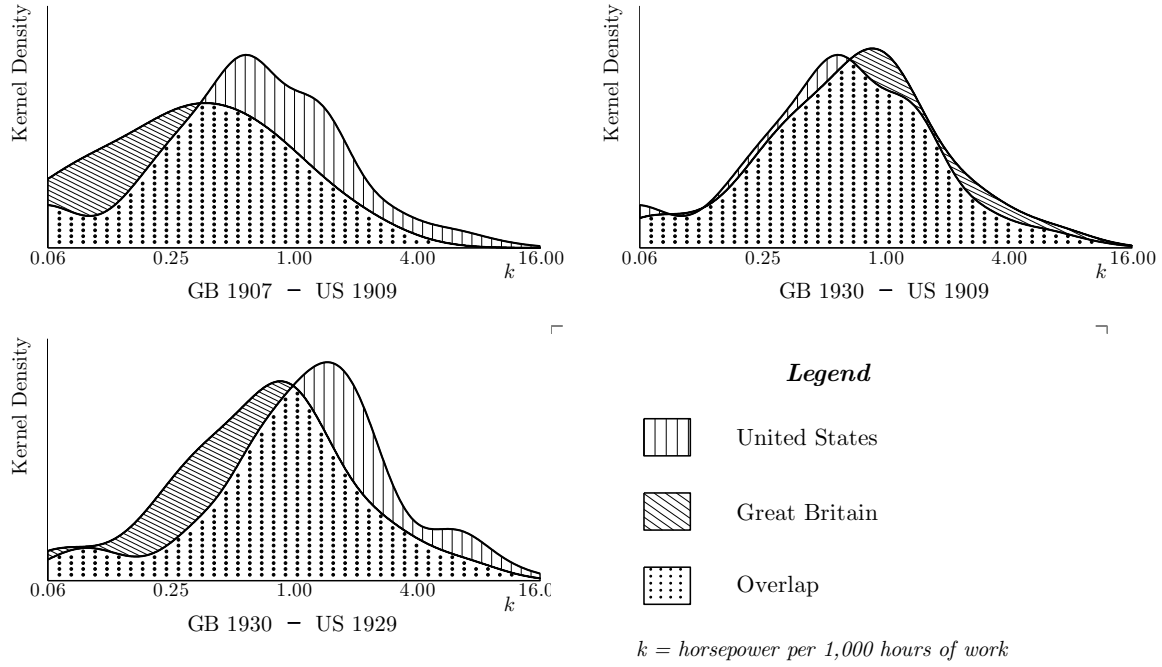
Both American and British performance was relatively strong during this period.¹³ Nonetheless, labor productivity growth in the US was considerably faster, and overall the productivity gap increased by approximately 1.2 percent per year. As table 1 illustrates, the drivers behind the widening of the productivity gap were relatively slow technological change and general efficiency decline in British manufacturing industries. However, the process of capital deepening proceeded at a considerably higher rate in Britain, in turn decelerating the divergence process. Below, I will argue that the substantial accumulation component represents a general movement of a number of modern British industries toward American production techniques, thus partially bridging the technology gap that arose during the nineteenth century. In the short run, the gainful impact of this capital-deepening process on British industrial performance was weakened by a drop in efficiency, most likely resulting from learning-by-doing effects and other barriers that raised the cost of adopting a higher level of technology.

Figure 5 illustrates the bridging of the transatlantic technology gap. It presents the distribution of manufacturing employment over available production techniques (proxied by machine intensity) for both the US and Great Britain. During the first half of the twentieth century, capital-intensity levels were converging and by 1930 Britain had already surpassed the 1909 American level. In 1907, British manufacturing employed, on average, 0.48 horse-

12. For the total manufacturing estimates I weight technological change for all the underlying observations by their value added shares. In this aggregation I included only the observations from the start- and end-year for the growth decomposition.

13. Note that the annual productivity increases listed in table 1 correspond closely to the growth rates reported by Feinstein (1976, T111–3, 129, 131) for the UK and Kendrick (1961, 465–6) for the US. British manufacturing output rose, on average, by 1.2 percent per year between 1907 and 1930, while total employment and the average annual hours-of-work declined by 0.1 and 0.6 percentage points respectively. American manufacturing output grew by 4.2 percent annually between 1909 and 1929, while the number of persons engaged increased by 1.6 percent and average hours decreased by 0.9 percent during this period.

Figure 5: Distribution of capital intensity, US and GB



power per 1,000 hours of work in manufacturing. This ratio rose to 1.14 by 1930. In 1909, the American capital-intensity level was 0.98, which increased to 1.81 by 1929. The upper-right panel of figure 5 illustrates that, not only were the average levels merging, the interwar British distribution of employment over capital-intensity levels (i.e. production techniques) mirrored that of the US in 1909. Whereas the British distribution of production techniques before the First World War showed a distinct pattern – with a vastly greater percentage of workers engaged in capital-extensive industries and lacking the characteristic American tail of very capital-intensive production – the shape and range of the distribution of production techniques for Great Britain resembled that of the US halfway the interwar period. Prior to the Second World War, Britain still trailed the US by almost two decades, yet overall dissimilarities between production techniques used in American and British manufacturing industries disappeared to a large extent. While at the turn of the century both countries tracked different technical paths, such a distinction is no longer evident for the interwar period. The comparatively high rate of capital deepening in British manufacturing implies that initial conditions did not stand in the way of capital-intensive production.

The rapid rate of capital deepening explains nearly all of British labor-productivity growth between 1907 and 1930, as shown in table 1. The accumulation component for Britain is considerably larger than for its American counterpart, reflecting both a faster rise in capital intensity and the greater gains from capital deepening at lower levels of horsepower per

hour worked; the latter affirms the standard assumption of diminishing returns to capital-intensity. The general move of British industries toward American production techniques also led to an increase in the rate of technological change, since aggregate technological change generally exhibits a strong bias toward capital-intensive technologies, as discussed above. Nonetheless, the British rate of technological progress was still substantially slower than I observe for the US during this period. Lagging technological change in Great Britain remained a major contributor to the widening of the transatlantic productivity gap.

The final component in the Kumar and Russell decomposition, efficiency change, represents the residual of the observed rise in labor productivity and the potential labor-productivity growth – the latter resulting from both capital accumulation and technology change. Timmer and Los (2005, 52) illustrate that the efficiency change can be interpreted as the result of learning-by-doing and indicates the extent to which a country has exhausted the potential of a particular technology (Barro and Sala-I-Martin 1997; Basu and Weil 1998). In addition to these ‘pure’ efficiency gains or losses, the residual efficiency term for aggregate manufacturing also includes the effects of structural change. Table 1 reports a small efficiency gain for the US between 1909 and 1929, which can, for the most part, be attributed to a favorable shift in the employment structure of American manufacturing. Over the course of these two decades, labor was transferred from low-productive textile production toward chemicals and machinery fabrication. Generally, pure efficiency, or the relative vertical distance of American industries to the world-frontiers, remained unchanged.¹⁴ British manufacturing experienced a similar shift in the employment structure, boosting aggregate labor-productivity growth.¹⁵ Nonetheless, the total efficiency component in table 1 for Britain is well below zero, thus suggesting a substantial decline in pure efficiency at the industry level. Between 1907 and 1930, British industries were thus unable to realize their full potential that came about through the process of rapid capital deepening and increases in technological change. Consequently, even though British manufacturing converged on the US in terms of capital-intensity levels, the Anglo-American productivity gap failed to narrow and, as is evident from table 1, even widened considerably during the interwar period.

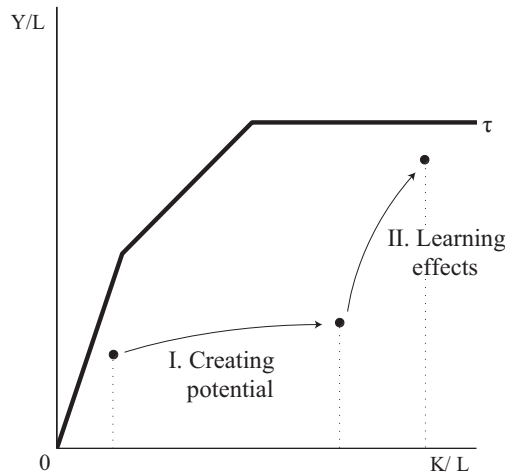
Delayed catch-up

In contrast to the literature I do not view the lack of catch-up growth as a failure on the part of British entrepreneurs. Previous applications of the DEA-approach led to findings resembling mine. For a sample of Asian countries, in the period between 1975–1992, Timmer and Los (2005, 58, 60) find comparable gaps between potential and realized labor-productivity

14. Note that, even though the US (as technology leader) dominated the world production frontier during the early twentieth century, I do observe several British and German observations that were located on the frontier, thus making it a truly ‘global’ frontier.

15. In Great Britain there was a substantial outflow of labor from the textile, apparel and leather industries, which in 1907 held a share of 43 percent of manufacturing employment but which declined to 33 percent in 1930.

Figure 6: Catch-up in two sequential steps



growth.¹⁶ Timmer and Los' interpretation of the Asian growth experience is based on Basu and Weil's analytical framework and rests on a two-tiered approach to catch-up. Follower countries go through two sequential phases of development in order to close the gap to the frontier, as depicted in figure 6.

The initial phase of catch-up, the adoption of new production techniques through the accumulation of capital, involves an extensive transformation of the production process. This causes efficiency levels to deteriorate in the short run. Only after the economy has successfully adjusted to the new state and has 'learned' to operate the new technology at its full potential, can the labor-productivity gap to the frontier be narrowed. This adjustment process was referred to by David (1975, 1–2) as 'learning-by-doing'. The time lag between creating potential and the movement toward the frontier depends both on the scope of capital deepening and on the flexibility of the economy and its institutional arrangements. For the case of Britain this implies that the implementation problems that engineers and industrialists encountered in the 1920s and 1930s were not signs of failed industrialization. Instead, they were features of modernization and inextricably linked to the initial phase of catch-up growth.

Sectoral decomposition

Although the above discussion reveals a clear pattern in the widening of the total manufacturing labor-productivity gap, it masks the underlying dynamics in the British-American

16. Particularly for Korea – the country that experienced one of the fastest rates of capital deepening – the relative distance to the global frontier increased over time. Overall, Korea grew 3.8 percentage point less than the 9.3 percent annual growth potential it had created. Instead of interpreting the negative efficiency component as a failure, Timmer and Los conclude that these findings suggest a possible sequence in which countries first create opportunities for growth by rapidly increasing capital intensities and only later start to benefit from technology spillovers.

convergence process through the aggregation of industries. Table 2 captures the average annual growth rate of British and American labor-productivity at the industry level.¹⁷ British manufactures showed a comparatively strong performance in the textiles, apparel, leather, building materials and instruments industries.¹⁸ These industries experienced relatively slow rates of technological progress and suffered less efficiency decline, which led to a comparatively modest increase of the Anglo-American labor-productivity gap. In contrast, labor-productivity levels diverged most in the industries closely associated with the Second Industrial Revolution; namely, transportation equipment, chemicals, petroleum and rubber. These ‘modern’ industries experienced exceptionally rapid rates of global technical advances and exhibited a strong bias toward uneven factor saving. During the early twentieth century, the acceleration in the (localized) technological change induced British entrepreneurs to adopt American-style, capital-intensive, production techniques, as evidenced by the greater accumulation component for most notably the transportation-equipment industry. As observed for aggregate manufacturing, the Anglo-American technological convergence (through the rapid British capital deepening) led to a substantial decline in efficiency levels in Great Britain for these modern industries.

A marked example of the adoption of American-style, capital-intensive production techniques in Britain at the industry level is the chemicals sector. This sector encompasses the chemicals, petroleum, coal- and rubber-products industries which, during the early twentieth century, experienced an unprecedented rate of productivity growth. Between 1909 and 1929, American labor productivity in the chemicals sector grew by 4.6 percent annually, over 3 percentage points of which was derived directly from technological change. This technological change was strongly biased toward capital-intensive production techniques, as illustrated by the industrial-chemicals sector in figure 4. As British producers in the chemicals sector were initially operating on a technical level outside the range of the world’s technology leader, the contribution of technological change to British productivity growth fell well short of that of the US, widening the Anglo-American productivity gap by 0.8 percent annually. Comparatively rapid British capital deepening in the chemicals sector more than offset the effects of technological change, however. Table 2 shows that the potential for growth in British chemicals – i.e. the sum of the technological change and accumulation components – actually surpassed that of its American counterpart. Yet, the shift toward more capital-intensive methods of production and the rapid technological change led to a deterioration of efficiency in Great Britain, preventing British chemical producers from realizing their full potential. Overall, the Anglo-American labor-productivity gap in this sector widened by 3.3 percent per annum. I observe similar dynamics in the other modern industries, particularly

17. The estimates in table 2 show labor productivity growth and its decomposition for the main industry groups within manufacturing. Appendix F provides the results for the full breakdown of the manufacturing sector, including all SIC two-digit industries.

18. Note that the instrument-producing industries are part of the miscellaneous category in table 2. See appendix F for a full breakdown of the manufacturing sector.

Table 2: Decomposition of labor-productivity growth, manufacturing industries, US and GB

	<i>annual average growth rate, in ln%</i>			
	<i>total</i>	<i>accumu- lation</i>	<i>tech. change</i>	<i>effi- ciency</i>
<i>United States (1909–1929)</i>	<i>3.1</i>	<i>0.7</i>	<i>2.2</i>	<i>0.2</i>
Food & tobacco	3.1	1.5	1.9	-0.3
Textiles & apparel	2.3	0.5	1.9	-0.1
Paper & printing	3.6	1.1	2.4	0.2
Chemicals & rubber	4.6	0.8	3.2	0.6
Building materials	3.3	0.4	2.4	0.5
Metals	2.5	0.4	2.0	0.2
Machinery	2.2	0.1	1.5	0.6
Transportation equipment	8.2	2.0	5.6	0.6
Miscellaneous	1.9	0.3	1.8	-0.2
<i>Great Britain (1907–1930)</i>	<i>1.9</i>	<i>1.7</i>	<i>1.4</i>	<i>-1.2</i>
Food & tobacco	1.8	2.3	1.2	-1.7
Textiles & apparel	2.5	1.2	1.6	-0.4
Paper & printing	2.5	3.3	1.2	-2.1
Chemicals & rubber	1.3	1.9	2.3	-2.9
Building materials	2.1	1.0	1.5	-0.4
Metals	0.7	1.1	1.3	-1.7
Machinery	0.5	0.5	0.4	-0.5
Transportation equipment	3.6	3.6	3.0	-3.0
Miscellaneous	1.3	3.0	0.5	-2.1
<i>Difference (US-GB)</i>	<i>1.2</i>	<i>-1.0</i>	<i>0.8</i>	<i>1.4</i>
Food & tobacco	1.3	-0.8	0.7	1.5
Textiles & apparel	-0.2	-0.7	0.2	0.3
Paper & printing	1.2	-2.3	1.2	2.3
Chemicals & rubber	3.3	-1.0	0.8	3.5
Building materials	1.2	-0.6	0.9	0.9
Metals	1.8	-0.7	0.7	1.9
Machinery	1.7	-0.4	1.1	1.1
Transportation equipment	4.6	-1.6	2.6	3.6
Miscellaneous	0.6	-2.6	1.3	1.9

Sources: see section 2; May not sum to total due to rounding.

transportation equipment, but also electrical machinery, paper, printing and to a lesser degree metals. Again, I distinguish stronger technological change in the US, which was biased toward capital-intensive production techniques, coupled with considerably faster capital accumulation in Great Britain. Similarly, for these industries I also observe a severe deterioration in British efficiency levels.

For the textiles, apparel and building materials industries table 2 reveals a different pattern. Here, I do not observe the rapid decline in British efficiency levels. Moreover, for these industries the gap in the Anglo-American labor-productivity levels rose less than the manufacturing average. In the case of the textiles and apparel industries this gap even declined slightly over the course of these two decades. As a result of relatively slow, unbiased, technological change, British producers lacked the incentive to diverge from the original, labor-intensive technological path. This deterred them from adopting American production techniques as avidly as we saw for the modern industries. The dichotomy of technology paths is also evident in the foods sector. Even though the accumulation component for this British industry was relatively large, by 1930 the British capital intensity level in the foods sector was still well below the American level in 1909 (0.70 versus 1.12 respectively). In the production of food, as was the case for textiles, British industry was clearly operating on a different part of the technology frontier compared to their American competitors.

The traditional explanation of differences in factor endowments, which will affect all industries equally (at least in the case of the availability of labor), is unable to explain the apparent divide in the rate of adoption of American, capital-intensive production techniques across the different manufacturing sectors. The industry-specific rate and bias of technical progress provides a credible explanation why British entrepreneurs in the textiles and building materials, but also in the food industries, continued to track a labor-intensive path of production, whereas, at the same time, the producers of chemicals, printing and transportation equipment diverged from this path and actively sought to adopt new, capital-intensive, production techniques. The disaggregate decomposition above shows that only those British industries that experienced strongly biased technological change were drawn toward these more capital-intensive ways of production. Moreover, particularly those industries that diverged from their original technological path experienced a clear worsening of their relative technical efficiency. As noted in the previous section, the convergence in terms of capital intensity and production techniques led, in the short-run, to a widening of the Anglo-American labor-productivity gap. Regardless, the modern industries showed strong growth potential, the fruits of which could be reaped when the (initial) barriers to the successful adoption of the new production techniques were overcome and producers learned to operate the new technology at its full potential. In line with this reasoning, during the first two decades following the Second World War, the British manufacturing sector experienced significantly stronger trend growth than the US and the two countries gradually started to converge in terms of labor-productivity levels (Crafts and Mills 1996, 421).

4 Barriers to British productivity convergence

I am certainly not the first to study Europe's inability to close the transatlantic productivity gap during the first half of the twentieth century, and I consider the analysis applied in this paper to be complementary to previous work discussing the constraints to British labor-productivity growth. The non-parametric growth decomposition presented in this paper uncovers the large discrepancy between created growth potential and realized growth. In turn, the existing literature can provide a better understanding of the impediments to technological transfer and the causes behind the pronounced decline in efficiency within British manufacturing. Although it is not my intent to offer an exhaustive overview of the literature, I aim to link the key mechanisms of my model to the realities of interwar Britain.

The argument made by Broadberry (1994) is that Britain failed to adapt to the changing conditions of the interwar years and, in the face of different endowments and demand patterns, continued to pursue a crafts-based production system, losing both productivity and technological leadership to the American system of mass-production. Consequently, Broadberry argues, British manufactures allowed relative productivity levels to fall, under-invested in new machinery (and hence production processes), failed to modernize its management, under-equipped its labor force with relevant skills and embodied a myriad of restrictive practices which prevented industry from realizing its potential (Bowden and Higgins 2004, 384). Section 3 of this paper presents a rather more dynamic view of British manufacturing. I show that a sizable part of British manufacturing was drawn toward the more capital-intensive, American ways of production and exhibited substantial growth potential. In this section I will illustrate that, in these key industries, British entrepreneurs did indeed introduce modern, mechanized production techniques, invested in continuous-flow manufacturing and adopted new techniques of managerial control. By confirming that Britain was successfully adapting to the rapidly changing environment, I can reject the premise that the entire manufacturing sector was locked into a separate technology path and prove that technology transfer did occur. I do argue however that, in the case of Britain, the adoption of modern production techniques was severely hampered by government intervention in an attempt to correct for market failures, the dominance of craft unions and pre-existing work practices that proved hard to displace. These institutional impediments explain why technological diffusion was not as widespread, and the convergence of technological paths did not occur as quickly as observed in the case of Germany for instance (van Ark 1993, 86–7; Crafts and Mills 2005, 650; Crafts 2012b, 22–3).

Below, I discuss the impact of these institutions, both on the reluctance of British manufactures to move into the new, dynamic industries that emerged during the early twentieth century, as well as the relatively hesitant adoption of capital-intensive production techniques within some of these industries.

British technological change

To illustrate the introduction of mechanized production techniques in British manufacturing I once again turn to the transportation equipment industry. This industry experienced, as I illustrated in the previous section, exceptionally rapid rates of global technical progress which exhibited a strong bias toward uneven factor saving. I argue that these technological advances induced British entrepreneurs to adopt American-style, capital-intensive production techniques in order to bridge the productivity gap that had arisen during the previous decades. The rapid capital deepening was reflected in a particularly large accumulation component, which, between 1907 and 1930, accounted for almost all of British labor-productivity growth in this industry. In the age of growing private motor ownership and ‘Fordism’, it was the motor vehicles industry that particularly stood out in terms of technological progress (Field 2011, 70). Yet it was also this industry where British engineers have been criticized for their failure to adopt American mass-production methods (Lewchuk 1987). As argued by Bowden and Higgins (2004, 386–7), prior to the Second World War, Britain lacked a mass-market for automobiles as demand was limited to the middle and upper classes. The British consumers placed a particularly high premium on the performance and quality of their motor vehicles and were less concerned with price constraints. Hence mass-production, as espoused by Fordism, was not a viable option for British producers.

Nonetheless, the interwar years did witness significant investment in the British motor vehicle industry. The fact that it was not Fordist does not invalidate it. The annual growth rate of total capital in the vehicle industry – which Matthews, Feinstein, and Odling-Smee (1982, 241) estimate to have been 3.1 percent – was among the highest in British industry in the interwar years. The 1920s and 1930s witnessed large investment programs undertaken by the major motor vehicle producers with the gradual introduction of mechanized production techniques, assembly lines and specialized machinery used to produce individual items on a continuous basis. British producers of motor vehicles were following the path set out by the American vehicle industry. In 1923, for example, a major investment program in continuous flow production began at Longbridge as a result of which this site became the first motor works in the country with a moving assembly line for the production of chassis and car bodies (Bowden and Higgins 2004, 386–7).

These modernizations were not exclusively confined to the motor vehicle industry. During the First World War, in the industries essential to the war effort, scientific management techniques such as time-and-motion studies were applied in order to maximize output and efficiency. Machine tools were imported from the United States and installed in the factories where they were previously unknown. Automatic welding spread through the shipyards. Eichengreen (2004, 320–1) notes that “the installation of automatic machinery allowed a growing number of operations to be undertaken by workers with minimal training. In this way, British industry took a first tentative step down the road that led to modern mass-

production as in the United States.”

The move toward capital-intensive production techniques was not apparent in all industries, however. The textiles industry proved to be highly reluctant to invest in new production techniques and technological change. In the previous section I showed that this industry experienced a relatively modest rate of unbiased technological progress and that both American and British producers were disinclined to invest in this industry. As a result, the technology gap, that had opened up during the nineteenth century, remained wide. In accordance with the Broadberry view, the two countries continued to track a different technological path in this industry. This is most obvious for cotton textiles, which was the focus of a case study by Lazonick (1981). Lazonick argued that the cotton textile industry failed to modernize by re-equipping with ring spinning and automatic looms. Whereas, during the interwar years, ring spinning capacity was the dominant spinning choice in the world, the British cotton textile industry still relied heavily on mule spinning. The relative importance of rings in the UK remained low at just around 23 percent (Bowden and Higgins 2004, 386). Consequently, by this time a large proportion of British cotton spinning machinery had become technically obsolete. Sandberg (1969) argued that demand and relative factor costs were the main reasons why English spinners persisted with mules, rather than an aversion to new technology.

The reluctance to adopt new production techniques is apparent for most traditional industries. My estimates indicate that industries such as building materials, clothing and textiles showed little or no sign of convergence in terms of capital intensity levels. Whereas newer industries, such as chemicals, petroleum, transportation equipment, and printing did exhibit rapid capital deepening and technological catch-up. The experience within these industry-groups was not uniform however; the capital deepening process in the transportation equipment sector, for instance, was primarily driven by investment in the motor vehicle and aircraft industries, while the more traditional shipbuilding and railway carriage trades continued to track a labor-intensive production path. In the case of the engineering sector, it was the electrical engineering industry that exhibited a high growth rate of its capital stock and witnessed a dramatic increase in the range of items produced (Matthews, Feinstein, and Odling-Smee 1982, 241). Even though the transformation of British manufacturing was hesitant and mostly limited to the more dynamic new industries there was cause for cautious optimism. Eichengreen (2004, 341) remarked:

“By the end of the 1930s some 250 British firms had adopted modern techniques of managerial control (including the multidivisional firm). Modern cost accounting had been installed, and top management was being professionalized. Spending on research and development tripled over the course of the decade. New products and processes proliferated, fueling hopes of the emergence of a ‘development bloc’ of modern industries.”

The ‘new’ industries

The role played by the new industries has been emphasized in the literature before (Richardson 1961; Buxton 1975; de Jong 2003, 108–9). Notably, Richardson (1962, 360–1) ties the robust British growth performance experienced during the interwar period to these modern industries. This view was backed by evidence of a revival of TFP growth during the 1930s, as well as a strong emphasis on the quality of modern investment and the structuring of British industry toward these growth-oriented sectors (Matthews, Feinstein, and Odling-Smee 1982; Pollard 1983, 53). In addition, Richardson stresses the technical developments and the introduction of new processes, production methods and products in these industries, whose progress he considered to be largely interdependent. In the more recent historiography the growth performance of the British economy during the 1920s and 1930s and the role played by the new industries has been viewed more critically, however. Broadberry (1983, 466–8) shows that structural change within manufacturing was not particularly pronounced during this period, while overall productivity growth was not especially fast. Also, Crafts (2012b, 21) stresses the fact that productivity and TFP growth in the UK remained well below the standard set by US industries during the first half of the twentieth century. As a result, on an hours-worked basis, the labor-productivity gap between Britain and the US in manufacturing continued to widen up to the 1950s. The direct Anglo-American benchmark for 1935 by de Jong and Woltjer (2011) also reveals that particularly the modern British industries (engineering, transportation equipment and chemicals) performed poorly in comparison to their American counterparts.

The poor productivity performance of particularly the new industries in Britain does not appear to favor the ‘optimistic’ interpretation by Richardson, nor does it accord well with the wave of modernization described above. However, as previously noted, TFP growth consist of both improvements in technology as well as efficiency with which the factors of productions are used (Crafts 2012a, 7). My decomposition allows for the breakdown of TFP in both these components. In table 3 I recast the results from section 3 in terms of ‘new industries’ and ‘old staples’, in line with the distinction made by Richardson (1965, 250) as well as Crafts (2004, 20).¹⁹ This decomposition contrasts the strong growth potential of the new industries against the slower, yet almost fully realized potential in the old staples.

Table 3 confirms the fact that, in British manufacturing between 1907 and 1930, hourly labor productivity in the new industries grew slightly faster than in the old staples. In addition, it corroborates Crafts’ claim that productivity growth in the British industries remained well below the standard set in the US and that, in international perspective, the old staples performed comparatively better than the new industries; as the latter lost considerable less ground to the American producers. The decomposition also reveals, however, that the potential for growth in the new British industries was substantially greater than was the case for

19. The label ‘new’ refers to industries generally associated with the Second Industrial Revolution.

Table 3: Decomposition of labor-productivity growth, new industries vs. old staples, US and GB

	<i>annual average growth rate, in ln%</i>			
	<i>total</i>	<i>accumu- lation</i>	<i>tech. change</i>	<i>effi- ciency</i>
<i>United States (1909–1929)</i>				
New industries	3.6	0.8	2.6	0.2
Old staples	2.5	0.4	2.0	0.1
<i>Great Britain (1907–1930)</i>				
New industries	1.8	2.5	1.7	-2.4
Old staples	1.7	1.2	1.3	-0.8
<i>Difference (US-GB)</i>				
New industries	1.8	-1.7	1.0	2.5
Old staples	0.8	-0.8	0.7	0.9

Source: see section 2; May not sum to total due to rounding.

the old staples. Capital accumulation alone was responsible for over 2.5 percent of annualized growth in the new industries, more than twice as large as the accumulation component observed for the traditional industries. This reflects the modernization process in British manufacturing that was, as discussed above, most pronounced in the new industries. The contribution of capital deepening to American productivity in the new and traditional industries was substantially smaller, and the gap between the US and Great Britain arguably demonstrates the technological convergence that took place during this period. As technological change still progressed at a considerably higher pace in the US compared to Britain, however, it is clear that technological convergence was far from complete by 1930.²⁰

Institutional constraints

As illustrated above, only those British firms that were part of the new industries that in the US had benefited most from the advent of electrification, mass-production, and the introduction of professional management chose to risk the expenditure required for the successful adoption of these modern, capital-intensive, production techniques.²¹ Nonetheless, even in those British industries that chose to invest, the transformation to mass production lacked the vigor and dynamism that characterized the US and which was also apparent in Germany

20. One must bear in mind though that the technological change listed in table 3 is a geometric average and represents the vertical shift of the frontier both at the capital-intensity level of 1907 and 1930. In the British new industries, technological change measured at interwar capital intensity levels was more than double that of the period prior to the First World War (2.3 versus 1.0 percent). This large shift illustrates once more the biased nature of technological change during this period, at least for the modern industries.

21. For a detailed discussion of the impact of electrification on productivity change see, de Jong (2003, 154–61).

during the early twentieth century (Veenstra and Woltjer 2012). Below, I will highlight the role of institutions in the relatively hesitant adoption of capital-intensive production techniques in the more dynamic British industries.

For the motor vehicle industry, Lewchuk (1987) shows that British producers were reluctant to install new technologies as they wanted to limit their vulnerability to slowdowns, something which they could afford as a result of the protection imparted by tariffs and an oligopoly dominated by Morris Motors. Other sectors adopted similar anti-competitive behavior, which was sanctioned by government policy. As Britain was rapidly losing its dominant place in the world market, the interwar economy witnessed a major shift in supply-side policy as the British government became more and more willing to intervene in the market economy. Crafts (2004, 18) notes that, “among the innovations of this period were the beginnings of industrial policy in the 1920s, the general tariff of 1932, the encouragement of cartels and the imposition of controls on foreign investment in the 1930s.” The latter arrangements allowed firms to adopt conduct which avoided competition. Consequently, modernization and rationalization were no longer a prerequisite to survival. Instead, firms opted for a defensive strategy and engaged in collusive behavior (Bowden and Higgins 2004, 379).

Another institutional constraint to modernization in the interwar years was the rapid expansion of the craft unions. During the war, workers had been encouraged to join unions as a matter of public policy. Once freed from wartime restraints, the British unions became increasingly assertive (Eichengreen 2004, 320–1). “Menaced by the advent of skill-displacing technologies, which threatened to challenge their dominance of the workplace, craft unions used their power on the shop floor to enforce traditional practices in the workplace in terms of the numbers employed, training, routines and piece rates. Such attempts were more successful in industries like shipbuilding and cotton spinning, where skilled craft labor could not be easily replaced and was relatively better organized than its employers” (Magee 2004, 93). The craft unions had not yet established a solid foothold in the new industries, such as pharmaceuticals, automobiles and electrical equipment, which consequently led managers to face less opposition during the process of modernization. Admittedly, the high rate of unemployment witnessed during the interwar period eroded the bargaining power of unions, which may have enhanced the ability of firms to push for organizational and technical change. The rise of cartelization diluted the incentive for doing so, however (Eichengreen 2004, 341).

The imposition of an elaborate tariff system sheltered British manufacturing from foreign competition, which further weakened the need to increase efficiency and push for organizational change. Where the tariffs and the encouragement of cartels may have mattered most, however, was in retarding the transfer of resources to new uses (Eichengreen 2004, 338). As, in the 1920s and 1930s, demand weakened for the goods from the industries in which Britain had invested most in the nineteenth century (i.e. coal, iron and steel, textiles and shipbuilding) the market economy should have begun to reallocate resources out of these uses. Instead,

the British manufacturing sector was slow to move into the new industries. Several scholars have interpreted this slow transformation in terms of the handicap of an early start (Svennilson 1954; Frankel 1955; Kindleberger 1961; Ames and Rosenberg 1963). The experience and skills accumulated by coal miners and shipyard workers, for instance, were ill-suited to the more technologically sophisticated new industries. In addition, the old and new industries were often located in different places (Eichengreen 2004, 327–8). Buttressed by tariffs and cartels, British manufacturing continued to specialize in the old staples. This only stalled the difficult transition process. Productivity growth in the new industries was in fact faster than in other branches of manufacturing, a fact that suggests that Britain's relative overcommitment to the old staples reduced the manufacturing sector's overall rate of expansion and slowed down the modernization process.²²

The slower growth of demand in Britain did have additional consequences for the rate of technological change as well, by affecting the rate at which machinery was replaced. As noted by Salter (1966, 64–5), gross investment was the vehicle of technological change – since technological change was largely embodied in new capital equipment – and the rate of investment largely determined how rapidly new techniques were brought into general use and were effective in raising productivity. Slower demand therefore accounted for the frequently reported reluctance of British manufacturers to discard their old machinery at the same rate as their American competitors (Magee 2004, 82). Salter (1966, 72–3) showed that the best-practice plants in Britain reported similar capital intensities, applied identical production methods and had comparable levels of productivity compared to the best plants in the US. “The difference,” he claimed, “lies in a much higher proportion of plants employing outmoded methods in the United Kingdom.” The disparity in the ‘standards of obsolescence’ was one of the driving forces behind the Anglo-American productivity gap during the first half of the twentieth century. Nonetheless, the dichotomy of production techniques in British manufacturing, as observed by Salter, emphasizes once more that British producers did not eschew modern, capital-intensive, production techniques, but that its capital stock was simply slow to adjust to the rapid technological evolution of the time.

Another, often cited, factor that inhibited investment was the prevalence of family firms in the British manufacturing sector (Chandler 1990). It is argued that the relatively small British firms failed to capture economies of scale and scope inherent in new technologies. Opportunities which German and American manufactures seized both domestically and internationally (Nicholas 2004, 243). Yet, by international standards British firms were not exceptionally small. When comparing employment data, we see that the average manufacturing establishment in Britain employed 64 people, compared to 67 in the US, 14 in Germany and 26 in France. As emphasized by Magee (2004, 79–80), “The largest British chemical firm in 1903, United Alkali, employed over a thousand more workers than BASF, Germany's biggest manufacturer of the time. It was only in the heavy industries, such as iron and steel, that

22. See table 3, or Magee (2004, 78).

British plants were comparatively small.”

More generally, Elbaum and Lazonick (1986, 2) claim that the institutional legacy associated with atomistic, nineteenth century economic organization impeded the adoption of modern technological and organizational innovations. “Entrenched institutional structures – in industrial relations, enterprise and market organization, education, finance, international trade, and state-enterprise relations – constrained the transformation of Britain’s productive system.” Nonetheless, these ‘institutional rigidities’, did not prevent British firms in the new industries from adopting modern mechanized production techniques, investing in continuous-flow manufacturing and introducing modern techniques of managerial control. The supply-side policies of the interwar period merely served to slow the modernization process and retarded the transfer of resources to these new industries.

The lock-in hypothesis of British technical choice also presumes a static relation between the cost of capital and labor. During the interwar years, these relative factor costs were far from stable, however. Broadberry (1986, 469) shows that the average weekly hours fell by approximately 13 percent at a time when the real wage for a ‘normal’ working week was rising steadily. The raise in hourly labor costs was not matched by an immediate increase in the hourly labor productivity, making effective labor relatively more expensive in Britain (Eichengreen 2004, 324). At the same time, technical progress itself exerted continuous downward pressure on the cost of capital goods (Salter 1966, 35–6). The cheapening of capital goods relative to wages gave further impetus to the modernization and rationalization movement in British manufacturing, particularly in those industries where capital could be easily substituted for skilled labor.

British growth after the Second World War

Crafts (2012b, 22) shows that, during the period 1950 to 1973, “Britain experienced its fastest-ever economic growth but at the same time relative economic decline proceeded at a rapid rate vis-a-vis its European peer group such that by the end of the period Britain had been overtaken by [...] nine other [countries] in terms of labour productivity.” Following the Second World War, the interwar policies that reduced competitive pressures on British business change proved hard to displace and turned out to have long-lasting effects on output growth and productivity convergence. Even though a sizable portion of British manufacturing had successfully taken the first step in the Basu and Weil model and had created considerable potential for growth during the 1920s and 1930s, the implementation of the crucial second stage, ‘learning-by-doing’, proved to be more problematic. The process of learning-by-doing was, in the case of Britain, decelerated by an inflexible labor market and strong unions, as well as the cartelization and collusive practices previously described. As noted by Eichengreen (2004, 338), the industries that had implemented capital-intensive production techniques felt reduced pressure to optimize their efficiency levels, as tariffs and cartels

created a “cozy environment sheltered from the chill winds of competition.” Furthermore, British commitment to education and human capital formation lagged behind its major international rivals (Goldin and Katz 2008). Traditionally, Britain provided less basic education to its general labor force and directed educational reform toward clerical skills. This left the country relatively poorly placed to take full advantage of the new technologies introduced in the early twentieth century. “This was a legacy that was to cause twentieth-century difficulties,” as emphasized by Harley (2004, 175), “it was an efficient response to Britain’s position as the first industrialized country, perhaps, but a restraint on future growth.” As a result, Britain was less successful than other European nations in exploiting the opportunities for catch-up growth, gradually losing ground against her European rivals (Bean and Crafts 1996, 133). Nonetheless, as illustrated by Crafts and Mills (1996, 421), labor-productivity growth between 1951 and 1973 was considerably faster in the UK than in the US, resulting in the gradual decline of the Anglo-American productivity gap. The post-war productivity convergence supports the premise of a two-tiered process of catch-up growth that, for Great Britain, had its origins in the interwar era.

5 Conclusion

As noted by Tomlinson (2009, 228), the economic history literature on early-twentieth century British manufacturing has taken a rather despondent, or ‘declinist’, view. “Every industry or even company’s failure to match performance in another country has been commonly treated not as part of the rough and tumble life of global capitalism, or even as the result of contingent error and miscalculation, but rather as a symptom of profound economic, but also political, social and cultural malaise.” In part, Broadberry’s thesis that the divergence of Anglo-American labor productivity reflected the persistence of distinct industrial technologies in Europe and the United States, follows this tradition. He argues that, in the face of different endowments and demand patterns British producers continued to pursue a crafts-based production system, inevitably losing both productivity and technological leadership to the American system of mass-production.

This paper presents a rather more positive view of interwar British manufacturing, as I reassess the productivity dynamics on the basis of Basu and Weil’s model of appropriate technology, which predicts convergence in light of capital deepening. I show that a substantial part of British manufacturing, particularly the ‘new’ industries of the Second Industrial Revolution, was drawn toward the American mechanized production techniques and exhibited substantial growth potential. These new industries – i.e. chemicals, transportation equipment, electrical engineering and printing – exhibited strong rates of technological progress that was decidedly biased. Because of this bias in technological progress, labor productivity grew fastest for capital-intensive techniques during the first half of the twentieth century, which prompted British manufactures to rapidly increase their rate of capital deepening.

These findings are confirmed by examples of the introduction of modern mechanized production techniques, investment in continuous-flow manufacturing and the adoption of new techniques of managerial control. By confirming that parts of British manufacturing was successfully adapting to the rapidly changing environment, I can reject the premise that the entire manufacturing sector was locked-in a separate technology path, as argued by Broadberry.

However, in spite of these clear examples of British mechanization, the modernization process was severely hampered by government intervention in an attempt to correct market failures, the dominance of craft unions and pre-existing production practices. Supply-side policies of the interwar period slowed the modernization process and retarded the transfer of resources to new industries. The reluctance to adopt modern production techniques is particularly apparent for the traditional industries. My figures indicate that the old staples such as building materials, clothing, and textiles showed little signs of convergence in terms of capital intensity levels. Consequently, in contrast to Broadberry, in my estimates I do not observe a single development path for all manufacturing industries, but instead I find large heterogeneity in the modernization process within British manufacturing.

Even though British manufacturing converged on the US in terms of capital-intensity levels, the Anglo-American productivity gap failed to narrow and even widened during the interwar period. I show that, particularly for the modern industries, the capital-deepening process was accompanied by a large productivity growth potential which, however, did not materialize as low levels of technical efficiency stood in the way of convergence. Following Basu and Weil's appropriate-technology model, I interpret the decrease of relative efficiency as a feature of modernization inextricably linked to the first phase of catch-up growth, i.e. creating potential. Only after an economy has adjusted to the new situation and has exhausted the full potential of the new technology the labor-productivity gap to the frontier can be narrowed. In the case of postwar Britain this process of learning-by-doing was decelerated by an inflexible labor market and strong unions, as well as cartelization and widespread collusive practices. This 'institutional legacy' caused Britain to be less successful than other European nations in exploiting the opportunities for catch-up growth following the Second World War, thus causing her to gradually lose ground against her major European rivals. Nonetheless, the UK experienced significantly stronger trend growth than the US between 1951 and 1973 and the two economies converged in terms of labor-productivity levels.

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A Note on American data

The basic source of output, employment and capital data for US industries is the *Census of Manufactures*. Data on total employment, value added and total horsepower employed is available in the quinquennial censuses between 1899 and 1919 and the biennial censuses of 1923 to 1929 and 1939 (United States Department of Commerce 1913, 1923, 1933, 1942). In this appendix I will define the basic variables, discuss the comparability of the figures between different census years and clarify the industry classification.

Basic sources

Nominal value added is derived directly from the census figures as the net of the ex-factory value of products (the selling value at the factory or plants) minus the cost of materials, purchased fuel and electric energy and contract work. No attempt was made to adjust for inventory revaluations or fully account for maintenance work and repairs, but evidence presented by Fabricant (1940, 340–50) suggests that these adjustments would only marginally affect gross value added for the years in my sample. I calculated deflators at the industry level on the basis of the Fabricant (1940, 123–321, 605–39) indices of physical output and nominal output series.²³ Subsequently, I incorporated the modifications and extensions to the indices of production proposed by Kendrick (1961, 416–21, 467–75). Lastly, I reclassified these deflators to fit the 1945 Standard Industry Classification (SIC), which constitutes the basis for both the Kendrick series and my own.²⁴ Throughout, nominal value added was converted to constant prices (with a 1929 base) by applying the price deflators at the two-digit SIC level.

I define employment as the sum of wage earners, salaried officers and employees.²⁵ I exclude all proprietors and firm members as I wish to limit my analysis to manufacturing personnel whose activity directly contributes to the value added reported in the census. In censuses prior to 1935, manufactures were instructed to report all personnel employed in both production activities and in auxiliary activities such as maintenance, shipping, warehousing, etc. at the same location. My employment figures thus invariably include a number of employees engaged in these kinds of non-manufacturing activities. This distinction is complicated further by the 1939 schedule that asked employers to report separate figures for their manufacturing and non-manufacturing personnel, based either on- or off-site. Although it is difficult to establish to what extent this change in definition affects the comparability of the employment figures between the censuses, Fabricant (1942, 173) concludes that “the implicit census definition of factory employment has given rise to no serious ambiguities in the data.” For 1939 I included all non-manufacturing personnel in my employment totals

23. Note, 1939 physical output was derived from United States Department of Commerce (1952, 1).

24. For the computation of the aggregate price indices I maintained the Marshall-Edgeworth formula with 1909, 1919 and 1929 as base-years.

25. The category ‘salaried officers and employees’ includes all superintendents, managers and clerical workers.

while still excluding proprietors and firm members, which is compatible with the definition applied by Kendrick (1961, 434) for this year.

The census employment figures were converted to total hours worked on the basis of industry-specific average annual hours of work obtained from various sources. For the inter-war period I relied on data by Inklaar, Jong, and Gouma (2011, 852–4), who provide detailed estimates of average hours of work for wage earners.²⁶ I extended their dataset to include the census years prior to World War I. The censuses of 1909 and 1914 provide industry specific data on prevailing hours of labor per week; no data is available for the years 1899 and 1904, I used the 1909 average hours instead (United States Department of Commerce 1913, 316–9; 1917, 482–9). I normalized the industry-specific weekly hours over the total manufacturing figures provided by Jones (1963, 375), using census wage earners as weights. Lastly, I converted the prewar estimates to annual average hours worked, based on the 1900 estimate of American vacation and holidays by Huberman and Minns (2007, 546).

Capital intensity is defined as the sum of the horsepower capacity of prime movers and the horsepower rating of motors driven by purchased electric energy, divided by my measure of employment. This definition coincides with the census measure of primary power, which also excludes the power of electric motors run by current generated in the same establishment to prevent duplication. The census years 1921 and 1931 to 1937 were entirely excluded from my sample as data on power equipment was either not collected or incomplete for these years. Although it is likely that rates of capacity utilization have changed during my period of study, partly as a result of the shift from the use of prime movers toward electric motors, I was unable to adjust for these.

Scope and comparability

During the 1899–1939 period the scope of the activities covered by the census has changed somewhat. Prior to 1919, the American industrial census exempted all establishments with an annual production valued at less than \$500; for the years since 1919 this limit was raised to \$5,000. In the 1921 census report this resulted in a 21.6 percent reduction in the number of establishments covered. However, the comparability of the figures since 1919 were not appreciably affected as, according to the United States Department of Commerce (1942, 2), “99.4 percent of the total wage earners and 99.7 of the total value of products reported at that census [1919, red.] were contributed by the establishments reporting products to the value of \$5,000 or more.” In addition, from 1904 onwards, the Census of Manufactures was confined to establishments conducting work under the *factory system*, thus excluding neighborhood industries and hand trades. For 1899 I relied on reclassified figures provided in the 1909 census. The adjusted figures omit all non-factory establishments for 1899 and are thus

26. These figures relate exclusively to wage earners, however this group comprises the bulk of my employment measure, and any deviations in hours worked between wage earners and salaried officers and employees are bound to be small compared to the annual fluctuations observed during this period.

fully comparable to the statistics for subsequent census years (United States Department of Commerce 1913, 507–17).

Over the course of my period of study several major industries, engaged in activities no longer considered as manufacturing, were excluded from the census.²⁷ I followed this convention and withdrew these industries from my sample. Over the various censuses numerous changes were made to the classification of industries and products, inevitably resulting in discontinuities and breaks in the series. Fabricant (1940, 605–39; 1942, 179–230) discusses the continuity of the census value added and employment data over the period 1899 to 1939 at length. Overall, predominantly smaller industries were affected by the changes across the various census years, thus limiting the overall impact on the coherence of the data set. Where necessary, I have combined related industries into aggregate groupings to ensure continuity.²⁸

Standard industrial classification

In my analysis I rely on the industrial classification laid out in the 1947 Census of Manufactures (United States Department of Commerce 1949b, 862–914). The census classification was derived from the 1945 *Standard Industrial Classification* (SIC), which was the first attempt to standardize the collection and reporting of data across different agencies while maintaining consistency over a longer time-frame.²⁹ The industrial classification groups establishments primarily engaged in the same line or similar lines of economic activity which, in the case of manufacturing, is generally defined in terms of the products made (demand side) or the processes of manufacture used (supply side) (Kendrick 1961, 405–6). The SIC scheme places primary emphasis on the latter, whereas the original, prewar, census classifications relies heavily on the former.³⁰ The supply-side grouping of businesses – i.e. the categorization according to the way in which inputs are transformed into outputs, mainly depending on the technology used – fits neatly into my productivity study. Although the SIC has undergone several revisions (the latest in 1987), I explicitly chose to use the 1945 vintage as the introduction of new products and production techniques over time make the more recent classifications less applicable to the period preceding the Second World War.

27. Important industries that were dropped are motion picture production, manufactured gas, automobile repairing, and railroad repair shops; see e.g. Kendrick (1961, 404).

28. E.g. Cigarettes (211) and Cigars (212) were combined into an aggregate industry group as well as Flat Glass (321) and Pressed and Blown Glassware (322).

29. The differences between the 1947 census and the 1945 SIC are minor; for a detailed discussion see United States Department of Commerce (1949b, 931–3).

30. Although in many respects the SIC resembles the prewar census classifications, there have been a number of important changes that highlight the shift from a demand-side to a supply-side oriented classification. Notably in metals, the prewar censuses grouped establishments according to whether they produced ferrous or nonferrous products. The 1945 SIC reclassified these industry groups according to whether the production process was mainly associated with primary production (e.g. refining, smelting, rolling, etc.) or the production of finished metal products (e.g. nails, wire, hardware, etc.), regardless of the type of metal from which the end-product consisted.

Following the standard industrial classification, the manufacturing division comprises approximately 450 industries in 1939, which are included in 127 industry groups and 20 major groups. These major groups are commonly referred to as two-digit industries and are broken down into three-digit industries (i.e. industry groups), which in turn are separated into four-digit industries (Carter et al. 2006, 4:4). I restrict my analysis to the three-digit level, moderately modified to ensure continuity, leaving me with 105 observations for each of the 10 census years. I generally estimate a frontier at the two-digit level, implicitly assuming that industries share a production function at this level of aggregation. As previously noted, the SIC groups industries according to a similarity in their inputs, outputs or use of production techniques, giving credence to the assumption of a joint production function. For a number of two-digit industries this assumption was violated, in which case I estimate two or more frontiers for that respective group.³¹

31. The most notable example is *chemicals and allied products* (28) for which five separate technology frontiers were estimated. See table 4 for further details.

B Note on British data

The primary British data is taken from the First and Fourth *Census of Production* (Board of Trade 1912, 1933–5). In this appendix I will provide an in-depth discussion of the basic variables and methods of construction behind this data set. I explore the amendments required for changes in geographical coverage and discuss the exclusion of small firms. In addition, I analyze the comparability of the British and American data and review the steps required to make them analogous.

Basic sources

As was the case for the US, British output, labor and capital data is derived from the official production censuses. I selected the years 1907 and 1930, as both these surveys contain detailed information on gross output, intermediate inputs, employment and installed horsepower. Even though the terminology in the British and American censuses differ slightly, the concepts of value added, employment and horsepower capacity are equivalent for both countries. Gross output is again defined as the ex-factory value of products, whereas intermediate input represents the cost of materials, fuel and contract work. Value added, or net output, is the net of gross output and intermediate input and constitutes the sum of wages, salaries, rent, royalties, rates and taxes, depreciation of plant and machinery, advertisement and selling expenses and all other similar charges as well as profits.

As a first step in the construction of my data set, I reclassified the British industrial classification to fit the 1945 US Standard Industrial Classification (see appendix A). As was the case for the American data, I restrict the classification to the three-digit level. The level of detail in the British classification necessitated a number of modifications to the level of aggregation in order to maintain comparability and continuity over time.³² The resulting data set consists of 64 observations for both 1907 and 1930 and cover the British factory trades in their entirety.

Subsequently, I converted British output to nominal dollar values on the basis of the price conversion factors in Frankema, Woltjer, and Smits (2013) and de Jong and Woltjer (2011). In both these industry-of-origin studies the industry level conversion factors were calculated on the basis of producer prices, using the procedures first set out by Paige and Bombach (1959) and clearly explicated in the work of van Ark (1993). Note that the interwar PPPs rely on price data taken the Fifth Census of Production, which refers to the year 1935 (Board of Trade 1938–44). I extrapolated the interwar conversion factors to a 1930 base using price deflators taken from the work of Feinstein (1976, 61–9). The nominal dollar values were then converted to constant prices (with a 1929 base) by applying the American price deflators, discussed in appendix A above. Both the Anglo-American PPPs and the American

32. Particularly the British engineering trades lacked the detail specified in the US SIC. In this case I opted for the lowest feasible aggregation level based on the detail provided in the census.

price deflators were implemented at the two-digit SIC level.

For Britain I define employment as the sum of operatives (wage earners) and administrative, technical and clerical staff. In line with the definition used for the US, I include only those personnel whose activity directly contributes to the firm's production (thus excluding owners and firm members). I converted the 1907 employment figures to annual hours of work on the basis of Matthews, Feinstein, and Odling-Smee (1982, 566) estimate of the average number of weeks worked per year as well as weekly hours of work listed in the British Labour Statistics (Great Britain Department of Employment and Productivity 1971, 95).³³ For the interwar period I again rely on Matthews, Feinstein, and Odling-Smee (1982, 566), but base my estimate of the average length of the working week on a study by the International Labour Office (1939, 82–3).

For the British capital-intensity data I utilize the American formula of adding up horsepower of prime movers and of electric motors using purchased electricity. The 1930 census directly reports both the power available from prime movers and the horsepower of electric motors driven by purchased electricity. Unfortunately, no data is available for the horsepower capacity of electric motors in 1907 and I rely on figures of electricity purchased to estimate the horsepower of electric motors.³⁴ The prewar census does provide detailed figures on the total capacity of (non-electric) prime movers, however.

Scope and comparability

The 1930 census deals exclusively with industrial production in England, Wales and Scotland, whereas the 1907 Census of Production relates to United Kingdom as a whole. Fortunately, the 1907 census does provide separate figures for England and Wales, Scotland and Ireland.³⁵ To make the prewar census directly comparable to the interwar census, I excluded Ireland from the 1907 sample and rely exclusively on the production figures for Great Britain. This adjustment does not materially affect the productivity estimates, however, as only a fraction of industrial production in the United Kingdom took place in Ireland at this time.³⁶

33. Note that the figures for the average length of the working week are industry specific and refer to the year 1906.

34. Although my estimate of electric motors driven by purchased energy is fairly rough, its possible impact on the British capital intensity figures is limited as electric motors were still fairly uncommon at this time. Comparable figures for the US and Germany reveal that, prior to the First World War, less than 20 percent of the installed horsepower consisted of electric motors, while only a fraction of these were run by purchased electricity.

35. In some cases the Board of Trade chose to aggregate the production figures to prevent the disclosure of particulars relating to specific firms. The latter measure is taken primarily for small Irish firms that have no, or only a few, direct competitors within the confines of the country. Consequently, although my data for 1907 does, invariably, include some residual production figures for Ireland, the overall impact is limited on account of the small size of the firms in question.

36. The production in Ireland focused mainly on the textiles and food sectors and, overall, accounted for just 3.2 percent of net output and 4.2 percent of employment in the manufacturing sector of the United Kingdom (Board of Trade 1912, 18–9).

Comparability between both census years is affected by the exemption of small firms from the interwar schedule. At the 1930 census, firms employing ten persons or less were exempted from making detailed returns. Full returns were required from all businesses, irrespective of their size, at the 1907 census. Although the extent of the bias is difficult to determine, evidence presented by Rostas (1948, 25, 28–32) suggests that small plants and firms generally have a lower productivity than their larger counterparts. The exclusion of these firms from the 1930 schedule thus results in an overestimate of efficiency and productivity in comparison to the prewar numbers. In all, the proportion of the people working in British manufacturing employed by smaller firms is estimated in the 1930 census at approximately 10 percent (Board of Trade 1933–5, V:9–11,). On the basis of this proportion, Fremdling, de Jong, and Timmer (2007, 372–3) reckon that an upward bias of approximately 2 percent is introduced in the British interwar productivity statistics. As noted in appendix A, prior to the First World War, the US census exempted only those establishments with an annual production valued at \$500 or less. As the average output per person engaged in manufacturing amounted to \$2,560 in 1909, the scope of the American census is thus nearly as wide as the 1907 British census (United States Department of Commerce 1913).

C Distance functions

In this chapter I emphasize the role of technological change as a driver behind the wave of modernization that marked the interwar period and stress the importance of efficiency behind the British productivity dynamics of the 1920s and 1930s, particularly in relation to the US. Studies on technological change in the Anglo-American convergence debate have so far primarily been based on traditional growth accounting exercises. These studies assume that an economy is operating on its production function, and consequently, treat total-factor productivity (TFP) analogous to technological change. Such an interpretation is prone to serious limitations, however, as it usually requires several restrictive assumptions such as allocative and technical efficiency, factor-neutral technological change and constant returns-to-scale.³⁷ By adopting a data envelopment analysis (DEA), which applies non-parametric linear programming techniques, I can decompose TFP into two mutually exclusive and exhaustive components: [1] changes in technological efficiency and [2] shifts in technology over time. In addition, as the DEA does not require the imposition of a particular functional form on the production frontier, it allows for any type of technological change, be it biased or factor-neutral.³⁸

In this appendix I will summarize the basic framework behind the DEA, based primarily on the work of Färe, Grosskopf, and Lovell (1994). They illustrate that a distance function can be used to determine the Farrell efficiency indices of a production set for any number of inputs or outputs. In appendix D I will show that, on the basis of the efficiency scores, a (global) production frontier can be constructed, which in turn allows me to determine the change in technology over time (Färe et al. 1994, 68–9). In this basic example I assume that all inputs and output quantities are non-negative and that, for each time period $t = 1, \dots, T$, the production technology S^t models the transformation of N inputs, $x^t \in \mathbb{R}_+^N$, into M outputs, $y^t \in \mathbb{R}_+^M$

$$S^t = \{(x^t, y^t) : x^t \text{ can produce } y^t\} \quad (2)$$

The input distance function $D_i^t(x^t, y^t)$ at time t is defined as

$$D_i^t(x^t, y^t) = \min\{\theta : (\theta x^t, y^t) \in S^t\} \quad (3)$$

For the constant returns-to-scale case and a technology set S^t , the input distance function for

37. The number of restrictive assumptions within a growth accounting framework is primarily dependent on the choice of production function. A translog production function, for instance, is much more flexible than a Cobb Douglas specification and does not assume rigid premises such as perfect substitution between production factors or perfect competition. Nonetheless, the vast majority of growth accounting studies in economic history still rely on the restrictive Cobb Douglass production function.

38. The main advantage of the DEA technique is its flexibility and adaptability. A DEA allows for multiple inputs and outputs, does not require input- or output-prices and does not require behavioral assumptions such as cost minimization or profit maximization.

production $(x^{j,t}, y^{j,t})$ can be specified as

$$\begin{aligned}
& \min_{\theta, \lambda^1, \dots, \lambda^k} \theta \quad \text{subject to} \\
& y^{jt} \leq \sum_k \lambda^k y^{kt} \\
& \theta x^{jt} \geq \sum_k \lambda^k x^{kt} \\
& \lambda^k \geq 0 \quad \forall k.
\end{aligned} \tag{4}$$

The solution to the linear program for the intensity vector λ^* and efficiency index θ^* can be interpreted as follows. There is a (hypothetical) composite producer formed as a non-negative linear combination of all k observations using the components of λ^* . This composite producer consumes no more than θ^* times observation j 's inputs, while still producing j 's output. The composite producer thus represents a fully efficient producer who is located on the global production frontier at j 's output level, while θ^* represents the ratio between both the inputs of the composite producer and x_j^t respectively. Note that if $(x^t, y^t) \in S^t$, the Farrell efficiency index θ will take on a value between 0 and 1, where a value of 1 implies full efficiency.

The observations for which the input distance function returns a θ equal to 1 together determine the position and shape of the production frontier. The frontier is formed by tightly enveloping the fully efficient observations, or 'best practice' activities, with linear segments; as illustrated in figure 2 in the main text. The frontier is thus a subset of all feasible techniques that attain the highest labor productivity for the capital intensity levels they correspond to (Timmer and Los 2005, 52).

Although, so far I base my results on the assumption of constant returns-to-scale, Färe, Grosskopf, and Lovell (1994, 32–7) show that the flexible nature of the DEA allows me to relax this assumption. The constraint $\lambda^k \geq 0$ implies constant returns-to-scale. By controlling the intensity factor with additional constraints, i.e. $\sum_k \lambda^k \leq 1$ or $\sum_k \lambda^k = 1$, I can impose non-increasing and variable returns-to-scale respectively. The imposition of these additional constraints does come at a cost of greatly increased data requirements however. A sensitivity check on the basis of variable returns-to-scale, which can be found in appendix E, demonstrates that the constant returns assumption does not significantly alter the findings presented throughout this chapter; I therefore feel confident using it.

D Technological change

So far I have limited the discussion of the bias in technological progress to a graphical representation of the change for a small sample of manufacturing industries. In this section I will illustrate the graphical representation of the change in technology over time and subsequently discuss the observed bias in technological change for the remaining industries in my sample. This will allow me to determine whether, during the interwar years, technological progress was biased toward capital-intensive production techniques. Overall, I confirm the existence of a substantial bias in technological change. For a select number of manufacturing industries, however, I find evidence that suggests technological change was factor-neutral. For the latter industries, the pull toward American-style production techniques appears to be absent, whereas for industries that experienced strongly biased technological change British firms were drawn toward more capital-intensive ways of production.

Figure 7 presents a graphical representation of technological change. In this figure I return to the basic constant returns-to-scale case for two inputs (K and L) and one output (Y). In the left pane, observed production α and two frontier-technology sets are represented in $\langle k, y \rangle$ space, where y is labor productivity (Y/L) and k is capital intensity (K/L). The observation α is interior to the boundary of technology at time 0 and 1, and is thus technically inefficient. To find the fully efficient input mix for this observation – i.e. the intersect with the frontier – I utilize the input-based distance function introduced in equation (4). The distance function seeks the greatest proportional decrease in inputs, given the target output. In this example, the distance function yields θ^* which, for α , represents the ratio between the minimum amount of labor required and actual labor employed while still producing at least $Y(\alpha)$.³⁹ The maximum feasible productivity, at the technology level of period 0, is thus represented by

$$y_0^*(\alpha) = \frac{Y(\alpha)}{\theta_0^* L(\alpha)} = y(\alpha)/\theta_0^* \quad (5)$$

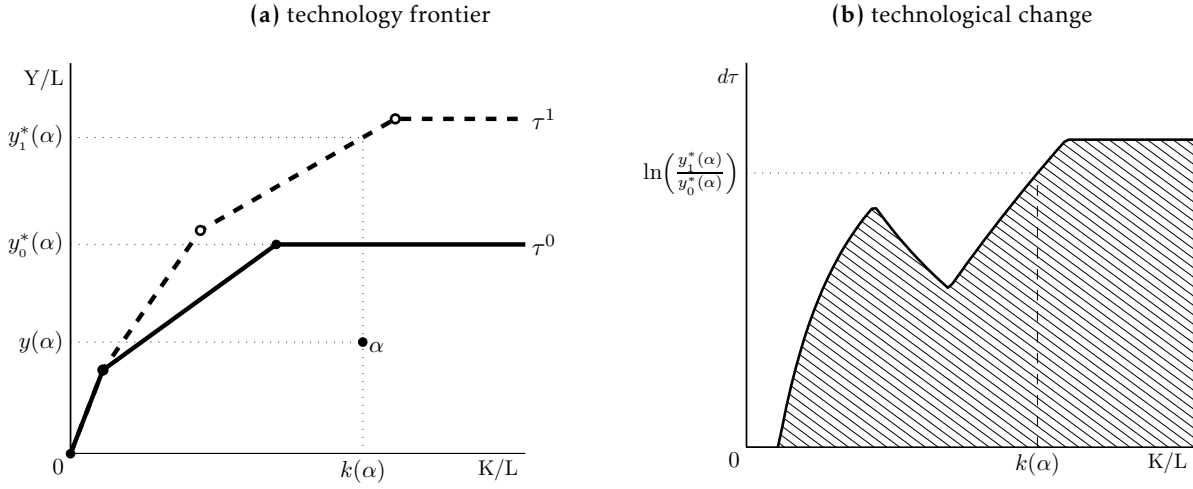
Technological change over time for α is represented in the left panel of figure 7 by the vertical shift of the frontier; i.e. the ratio between the maximum feasible productivity at time 1 and 0, or alternatively, the relative efficiency of α in period 0 divided by α 's efficiency with respect to the frontier in period 1.

$$\text{technological change} = \frac{y_1^*(\alpha)}{y_0^*(\alpha)} = \frac{y(\alpha)/\theta_1^*}{y(\alpha)/\theta_0^*} = \frac{\theta_0^*}{\theta_1^*} \quad (6)$$

The right panel of figure 7 depicts the log change of technology between the two periods (i.e. $\ln\left(\frac{y_1^*(\alpha)}{y_0^*(\alpha)}\right)$ or similarly $\Delta \ln(y)$) for both $k(\alpha)$ and any other feasible capital-intensity level

39. Note that θ^* represents this ratio for all inputs. The optimal capital intensity level for α is thus identical to its actual level, as $k(\alpha) = \theta^* K(\alpha)/\theta^* L(\alpha) = K(\alpha)/L(\alpha)$.

Figure 7: Frontiers and technological change



that falls within the technology set. The diagram thus depicts the relation between capital intensity and potential labor productivity change. As noted in section 3, the bias in technological progress can be gauged by the skewness of the diagram.

Figure 8 holds the graphs of technological change for all twenty-seven industry-groups in my sample; table 4 provides a brief description for each industry.⁴⁰ For the majority of manufacturing industries technological change exhibited a strong bias toward capital-intensive production techniques. For a select number of manufacturing industries, however, I observe no apparent capital-intensity bias in the rate of technological change, as discussed in the main text.

40. Note that for the SIC labels I followed the following convention. The first two digits refer to the major industry group, the third digit specifies the exact industries part of that group. A 't' is used to join all industries between the digits prior to and following the marker, 'n' joins only those digits actually listed (thus excluding those in-between), and the 'x' is used as a wild-card, referring to all three-digit industries that are not mentioned elsewhere; i.e. 20 refers to the entire two-digit SIC group 'Food and kindred products', 227 refers to the 'Carpets and rugs' industries which is part of the two-digit group 22, 'Textiles', whereas 22x refers to all remaining industries in this group. 357t9 concerns the industries 357, 358 and 359, while 371n25 refers solely to 371, 372 and 375.

Table 4: Characteristics of technology frontiers

<i>sic</i>	<i>description</i>	<i>sic</i>	<i>description</i>
20	Food and kindred products	29	Petroleum and coal products
21	Tobacco manufactures	30	Rubber products
22x	Textile mill products (misc.)	31	Leather and leather products
227	Carpets and rugs	32	Stone, clay, and glass products
23	Apparel and related products	33	Primary metal industries
24t5	Lumber and wood products	34	Fabricated metal products
261	Pulp, paper, and paperboard	35x	Machinery (except electrical)
26x	Paper and allied products (misc.)	357t9	Office and household machinery
27	Printing and publishing	36	Electrical machinery
281t2	Industrial chemicals	371n25	Motor vehicles, -cycles and aircraft
283	Drugs and medicines	37x	Transportation equipment (misc.)
284	Soap and related products	38	Instruments and related products
28x	Chemicals (misc.)	39	Miscellaneous manufactures
287t8	Fertilizers and oils		

Figure 8: Technological change

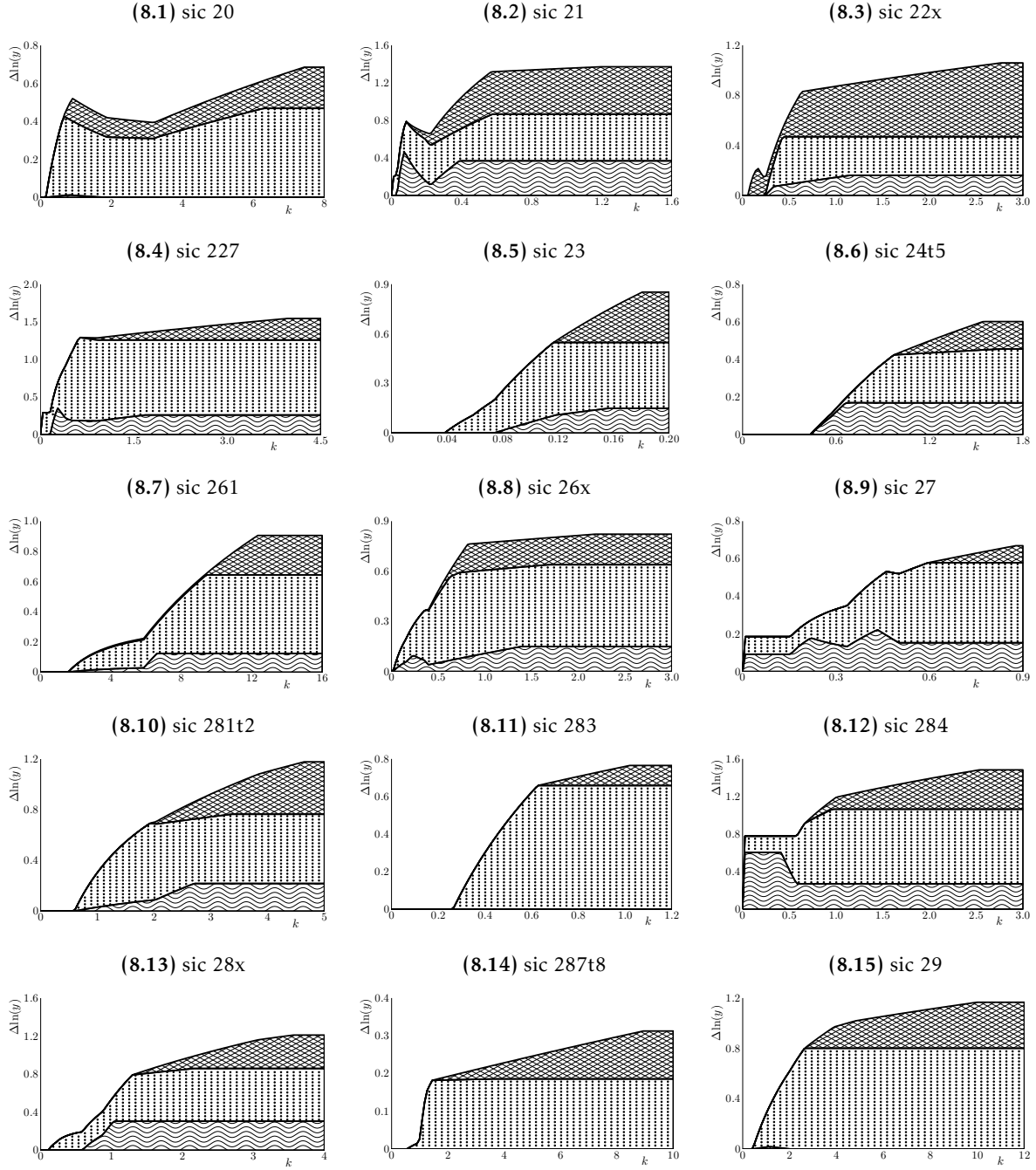
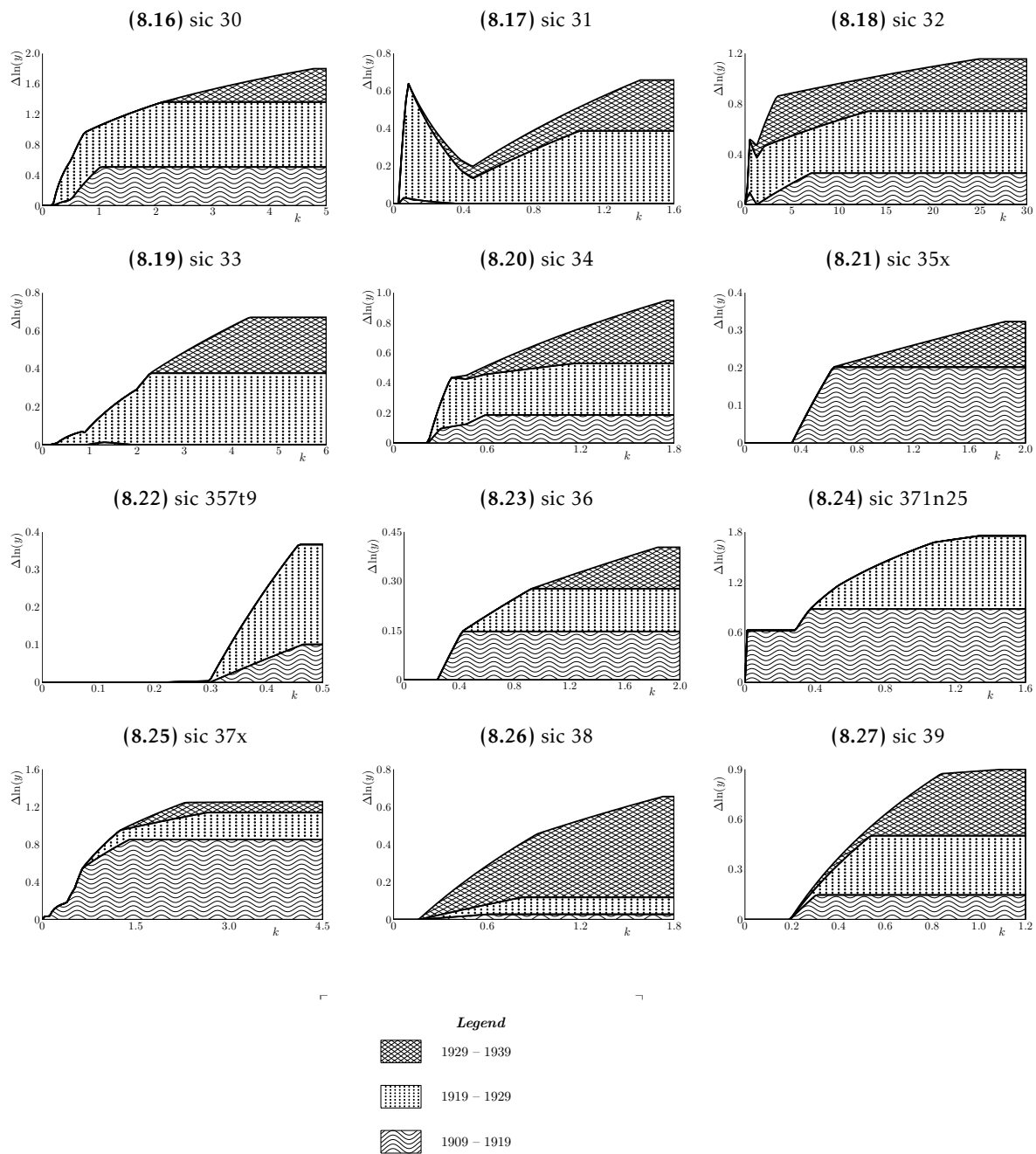


Figure 8: Technological change (continued)



E Robustness checks

In this section I consider several robustness checks that address three of the more vital assumptions that could lead my estimates to under- or overstate the effects of technological progress and efficiency change on productivity growth. First, I investigate the impact of alternative returns-to-scale models. Second, I consider the effects of estimating the production frontiers at the 3-digit SIC level. Lastly, I re-run my analysis on the basis of total employment instead of hours worked. I conclude that the constraints imposed throughout this chapter do not appear to bias the main results.

Returns to scale

Throughout this chapter I have based my decomposition results on the assumption of constant returns-to-scale (CRS). This assumption is only appropriate, however, when all industries are operating at an optimal scale, which can be frustrated by imperfect competition, constraints on finance, etc. In this case, the efficiency measures based on the CRS model are biased downwards by the occurrence of scale efficiencies. A variable returns-to-scale (VRS) specification excludes these scale efficiencies and envelopes the production points more tightly. Consequently, the latter yields technical efficiency scores greater than or equal to those obtained from the CRS model.

As noted in appendix C, the flexibility of the DEA permits me to relax the CRS constraint and assume VRS instead. The VRS specification does increase the requirements on the data set, however. A graphical representation of the frontier illustrates this problem. The two-input, one-output case would require the addition of a third dimension, as labor productivity is now not only dependent on the level of capital intensity but on the scale of production as well. Given the added dimension and the increased surface area of the frontier, a greater portion of the observations will form part of the (VRS) frontier and will thus be classified as fully efficient. The problem of unobserved production – either of represented countries in the past or of otherwise unrepresented peers – is thus confounded. What would now be interpreted as frontier movements could in fact be assimilation of knowledge associated with unobserved appropriate techniques. The VRS specification increases the degrees of freedom of the model, which could present identification problems for those frontiers for which I only have a limited number of observations. Nonetheless, if both models yield comparable results, we may conclude that the CRS assumption is appropriate for the interwar Euro-American productivity comparison. If, however, large discrepancies are observed in the decomposition results, this may signal that either my restrictive returns-to-scale assumption is not valid or that the VRS model suffers from insufficient observations.

The decomposition results for total manufacturing, based on both the CRS and VRS method, are provided in table 5. The table lists the aggregate results for the US and Great Britain separately. For the American decomposition, both the sub-period 1909–1929 as well

Table 5: Robustness checks, total manufacturing, US and GB

(a) US Manufacturing, 1909–1929				
	<i>annual average growth rate, in ln%</i>			
	<i>total</i>	<i>accumu- lation</i>	<i>tech. change</i>	<i>effi- ciency</i>
CRS	3.1	0.7	2.2	0.2
VRS	3.1	0.6	2.4	0.1
3DIGIT	3.1	1.0	1.9	0.2
EMP	2.5	0.5	1.7	0.3

(b) US Manufacturing, 1909–1939				
	<i>annual average growth rate, in ln%</i>			
	<i>total</i>	<i>accumu- lation</i>	<i>tech. change</i>	<i>effi- ciency</i>
CRS	3.0	0.8	2.0	0.3
VRS	3.0	0.9	2.0	0.1
3DIGIT	3.0	1.0	1.8	0.2
EMP	1.7	0.4	1.2	0.0

(c) GB Manufacturing, 1907–1930				
	<i>annual average growth rate, in ln%</i>			
	<i>total</i>	<i>accumu- lation</i>	<i>tech. change</i>	<i>effi- ciency</i>
CRS	1.9	1.7	1.4	-1.2
VRS	1.9	1.9	1.6	-1.6
3DIGIT	1.9	2.5	0.9	-1.5
EMP	1.2	1.5	1.1	-1.3

as the entire 1909–1939 period are given. Note that, while the annual log growth of labor productivity remains unaltered by the choice of a returns-to-scale model, the components of the Kumar and Russell decomposition can still be affected.

Overall, the differences between both models, at the highest level of aggregation, appear to be limited. Typically, the VRS model reports a mild increase of the accumulation and technology components, at the expense of efficiency. Yet, the general conclusions remain unchanged. American labor productivity is driven by rapid technological change and, to a lesser degree, capital accumulation. American efficiency change, for both periods, is small and can primarily be attributed to a gainful shift in the employment structure. For British manufacturing, the greatest contribution to labor-productivity growth results from capital deepening. Technological change in Britain, for the VRS model, still falls short of the progress experienced in the US, but is substantive nonetheless. Under the VRS specification, efficiency decreases considerably over time for Britain. As noted above, this may be caused by scale (in)efficiencies or alternatively an insufficient number of observations. In either case, the CRS assumption does not fundamentally alter my findings, I thus feel confident using it.

Frontier selection

In my analysis I have so far estimated a frontier for 27 industry groups. In the estimation of the frontiers I pool all the three-digit observations that belong to the same two-digit industry group, thus assuming that these observations share a production function at this level of aggregation. As an implicit check I observe whether the three-digit industries in a common group will, at any point in time, be part of, or closely approach, the frontier. Only a small number of industries failed to pass this simple test, in which case I estimated an additional frontier for these observations. Only the chemicals sector, whose industries proved particularly hard to group, required more than two distinct frontiers. Table 4 in appendix D provides an overview of the two-digit frontiers in this study.

Alternatively, I can estimate a separate frontier for each of the 105 three-digit industries in my sample. However, the increase in the number of frontiers does lower the average number of observations per frontier, which could present similar data problems as those previously discussed in the returns-to-scale section. Table 5 lists the decomposition results for total manufacturing based on this alternative frontier selection (3DIGIT), which can be directly compared to the basic, two-digit CRS decomposition. These two decompositions present a similar picture. For both countries, the technology component is lower than is the case for the standard CRS model, while the accumulation component is elevated. Particularly for Great Britain, the effect of capital deepening is more pronounced, accompanied by a more substantial decrease in efficiency. Nonetheless, the results based on the extended selection of frontiers are in broad agreement with the findings presented in the main text. As the impact of the alternative frontier selection is very similar for both Britain and the US and I am par-

ticularly interested in the difference in the development of capital deepening, efficiency and technological change *between* both countries, I conclude that the grouping of industries into two-digit frontiers is a valid approach for this study.

Employment

As a final robustness check I turn to the definition of employment. Throughout this chapter I relied on total hours worked as a measure of labor input, primarily because this measure captures the substantial drop in the average length of the working week that occurred during the interwar years. In contrast, previous productivity studies have often relied on basic employment measures – looking exclusively at the total number of active wage earners and employees in an industry – which thus makes comparison between these studies and my own analysis more difficult (Broadberry 1997). To facilitate this comparison and to determine whether a decomposition based on employment numbers (EMP) provides comparable results to my basic, hours-based decomposition (CRS), I have re-run the analysis on a per-worker basis and presented the results in table 5.

The reduction in the average length of the working week, which was evident in both countries, clearly shows in table 5. The total labor-productivity change for EMP is distinctly lower than my productivity measure based on hours worked (CRS), particularly when I include the 1930s in the analysis. The decomposition results reflect this reduction, but otherwise remain unaffected. For the US, technological change is still the driving force behind the change in productivity, while growth in Britain originates primarily from capital accumulation. In addition, for Great Britain I also observe a clear positive impact of technology accompanied by a worsening of efficiency. Nonetheless, I feel the EMP specification severely undervalues the impact of technological progress, particularly for the 1930s, which Field (2003) has shown to be one of the most progressive decades of the twentieth century. I therefore prefer the hours worked measure of employment.

F Disaggregate results

Table 6: Decomposition of labor-productivity growth, United States (1909–1929)

sic	description	annual average growth rate (ln%)					indus-tries
		total	accumu-lation	tech. change	effi-ciency	dK/L	
20	Food and kindred products	2.4	0.8	1.7	-0.2	2.3	8
21	Tobacco manufactures	6.4	4.3	2.4	-0.3	6.3	2
22	Textile mill products	2.3	0.1	2.3	-0.1	2.4	8
23	Apparel and related products	2.4	0.8	1.4	0.3	2.0	6
24t5	Lumber and woods products	1.7	0.2	2.0	-0.6	2.0	4
26	Paper and allied products	3.4	1.1	2.2	0.1	2.6	5
27	Printing and publishing	3.8	1.0	2.5	0.3	2.1	5
28	Chemicals and allied products	4.0	0.7	2.7	0.6	3.7	8
29	Petroleum and coal products	5.3	0.9	3.2	1.2	6.3	4
30	Rubber products	7.9	0.8	5.7	1.4	4.6	3
31	Leather and leather products	2.2	0.8	1.7	-0.4	3.4	8
32	Stone, clay, and glass products	3.3	0.4	2.4	0.5	4.6	7
33	Primary metal industries	2.3	0.4	1.7	0.2	2.3	4
34	Fabricated metal products	2.7	0.3	2.3	0.0	3.8	8
35	Machinery (except electrical)	2.2	0.1	1.6	0.5	4.2	7
36	Electrical machinery	2.2	0.2	1.2	0.8	2.4	2
37	Transportation equipment	8.2	2.0	5.6	0.6	5.1	5
38	Instruments and related products	2.0	0.1	0.2	1.7	3.6	6
39	Miscellaneous manufactures	2.4	0.7	1.7	0.0	3.2	6
D	MANUFACTURING	3.1	0.7	2.2	0.2	3.1	106

Table 7: Decomposition of labor-productivity growth, Great Britain (1907–1930)

sic	description	annual average growth rate (ln%)					indus-tries
		total	accumu-lation	tech. change	effi-ciency	dK/L	
20	Food and kindred products	1.3	2.3	0.8	-1.9	3.2	8
21	Tobacco manufactures	3.9	2.7	2.7	-1.5	5.2	1
22	Textile mill products	2.8	0.3	1.9	0.6	3.1	6
23	Apparel and related products	2.3	4.1	0.7	-2.5	6.1	3
24t5	Lumber and woods products	-0.9	2.0	0.4	-3.3	3.6	3
26	Paper and allied products	1.9	2.4	0.5	-1.1	3.7	3
27	Printing and publishing	2.7	3.7	1.5	-2.4	5.1	2
28	Chemicals and allied products	1.0	2.0	2.1	-3.1	4.5	6
29	Petroleum and coal products	1.2	1.2	2.4	-2.4	3.8	3
30	Rubber products	5.2	1.7	3.8	-0.2	5.3	1
31	Leather and leather products	1.0	1.4	1.8	-2.2	5.5	4
32	Stone, clay, and glass products	2.1	1.0	1.5	-0.4	3.5	4
33	Primary metal industries	0.1	0.5	1.3	-1.7	3.5	3
34	Fabricated metal products	1.9	2.4	1.3	-1.7	6.3	3
35	Machinery (except electrical)	0.0	0.6	0.4	-1.0	5.0	1
36	Electrical machinery	1.8	0.4	0.5	1.0	3.4	1
37	Transportation equipment	3.6	3.6	3.0	-3.0	4.8	4
38	Instruments and related products	2.6	2.9	0.1	-0.3	5.8	2
39	Miscellaneous manufactures	2.8	4.0	0.6	-1.8	6.5	6
D	MANUFACTURING	1.9	1.7	1.4	-1.2	3.8	64

